

The Coho Salmon of Cultus Lake and Sweltzer Creek

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ABSTRACT

A few hundred to one or two thousand cohoes enter Cultus Lake each year, while the Sweltzer Creek population below it is several times as large. "Jack" (age II) fish usually predominate over older male cohoes at the lake. Spawning in the lake or in tributary streams above yields downstream migrations of some hundreds of fry and, a year later, up to a few thousand yearling smolts. These, on the average, amount to 0.13 per cent of eggs in spawners, or only 3 smolts per female. This does not suffice to maintain the coho run into the lake, which is, therefore, heavily recruited from creek-bred fish each year. There are also a very few age-II seaward migrants, which largely return from the sea the same year. Of yearling smolts marked in 1927, 8 per cent returned to the lake after one and a half year's absence.

A large fraction, probably the majority, of yearlings produced in the lake fail to migrate from it and live there into their second or third year of life. They are readily taken by trolling or netting in the autumn of their second year and in the winter and spring of their third. Maturing fish of ages II (males) and III (both sexes) have been taken but they are scarce. For this or other reasons production of young by lake-resident cohoes is negligible, or perhaps altogether lacking.

INTRODUCTION

IN THE COURSE of the Fisheries Research Board's sockeye salmon investigations at Cultus Lake, B.C., considerable information was obtained incidentally concerning the coho salmon (*Oncorhynchus kisutch*) in the same body of water. The Cultus Lake investigations were taken over by the International Pacific Salmon Fisheries Commission in 1938, and information obtained since that time has very kindly been made available by Mr. L. A. Royal, the Commission's Director of Investigations.

The information on the Cultus Lake coho is of interest from two standpoints. For one thing it provides a sketch of the bionomics of the coho in a lake habitat, as contrasted with the usual stream habitat of this species. In addition, the comparison of coho and sockeye salmon in the same environment reveals interesting resemblances and contrasts.

The general outlines of the life history of the coho salmon in the Fraser River region are well known, largely as a result of age studies of scales taken from fish caught in salt water. Pritchard (1940) shows that the great majority of the coho taken by trolling on the coast of British Columbia are approaching three years of age at the time of their spawning migration. Spawning occurs during autumn or winter, and the eggs do not hatch until the following spring, so that it is necessary to date the fish's life from the time the eggs are fertilized in order to speak of a full three-year cycle. Scale study has also shown that a majority of young coho live in fresh water for about a year after hatching, that is, until they

are $1\frac{1}{2}$ years old from time of fertilization. In the usual shorthand, fish of this type are called "3₂" because they go to sea during their second year and return toward the end of their third. Although Pritchard found that 97.9 per cent of the commercial fish which he examined were "3₂'s", various other groups are present in the fishery in small numbers so that the complete spectrum obtained was 2₁, 2₂, 3₁, 3₂, 3₃, 4₁, 4₂ and 4₃. It is not certain that all these were maturing fish, though the majority of commercially-caught specimens are so. Sport fishermen take a large number of small 2₂ coho, which they call "grilse" and which probably include some individuals which would mature the same year and some which would not. When they enter a river, maturing 2₂ coho are called "jacks"; they are common in many streams (cf. Murphy, 1952), sufficiently so to show that the small number taken in the commercial fishery is probably not representative. At Cultus Lake they were quite numerous.

ANADROMOUS COHO

THE ADULTS

Coho run from the sea up the Fraser River and spread into most of its accessible branches. One of these is the Chilliwack or Vedder River, about 70 miles from the ocean; it in turn has as a tributary, Sweltzer Creek, a stream about two miles long, which has its source in Cultus Lake. This creek and lake have been the scene of fish-cultural activity from an early period. To obtain ripe sockeye salmon for artificial propagation three "fences" had been built across Sweltzer Creek about 1,000 feet below the lake. These are nos. 4, 5 and 6 in Figure 1. The uppermost, no. 6, had a series of traps and pens across the entire creek. Fences 4-6 were originally installed prior to 1920, but no. 6 was completely rebuilt in 1931. In 1932 three additional fences were built $1\frac{1}{2}$ miles downstream in the Indian Reserve, about a quarter mile from the junction of the creek with the Vedder River. These fences, nos. 1-3, were used for only three seasons, 1932-34. A seventh fence, called the "screen fence" or "yearling fence", was about 200 feet upstream from no. 6 and 800 feet below Cultus Lake; it was used to trap fish coming downstream, particularly salmon smolts.

Information concerning the adult anadromous coho in the Cultus system comes largely from the fences just described. The "regular" coho which enter Sweltzer Creek are commonly 21 to 30 inches long, averaging about 24 inches (53-76 cm., av. 61 cm.). They are presumed to be fish which have spent at least a year and a half in the sea, that is, predominantly 3₂. There also appeared every year a considerable number of the much smaller "jack" coho, which are presumably principally of the 2₂ age-group. Their range of size does not approach that of the larger fish, being about 10.5-13.5 inches in length, with an average of about 12 inches (27-34 cm., av. 30 cm.). Prior to 1931 they did not attract much attention because the palings of the salmon fences were spaced widely enough that most of them swam through without difficulty. In the new fence 6 installed in 1931, the palings were spaced closer together, and from that time a fairly large number of jacks was taken. However, it was not until 1935 that a count was made of them; from 1938 onward they were counted regularly. The

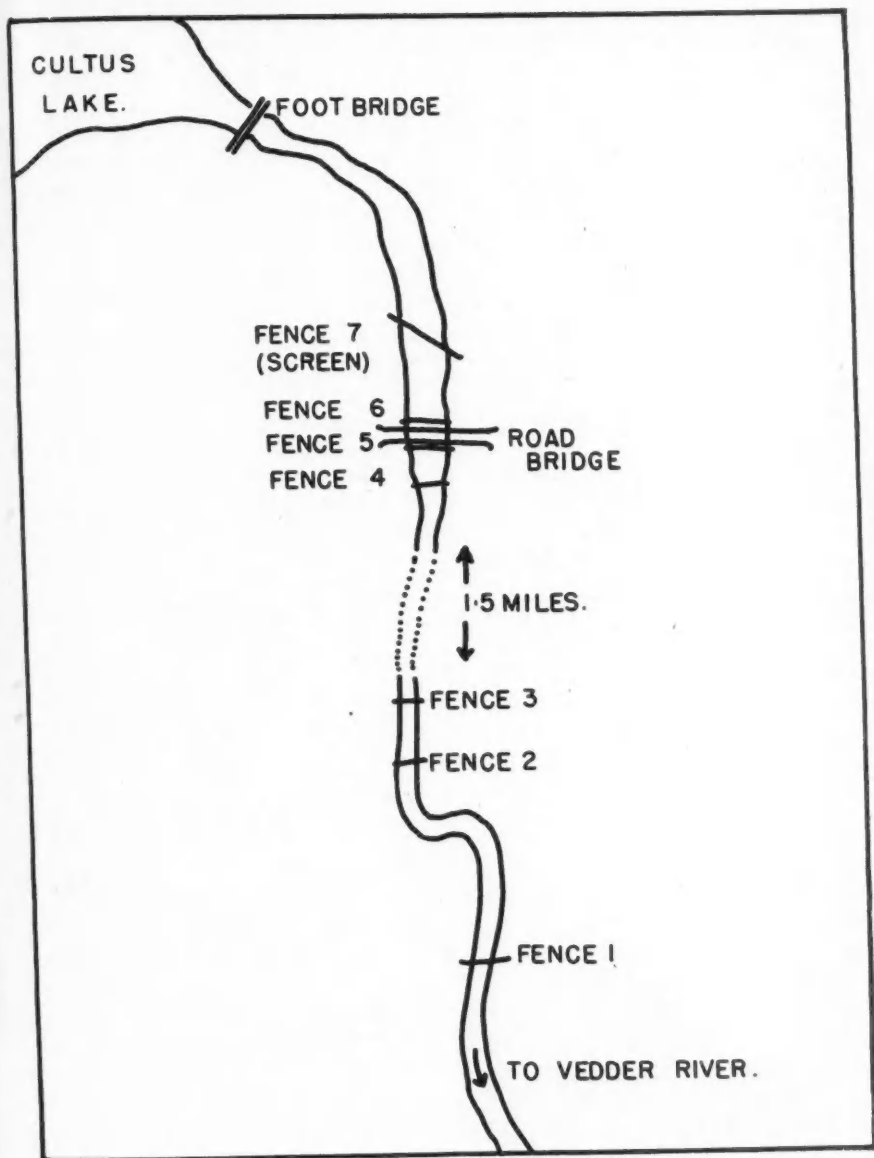


FIGURE 1. Diagram of the location of fences in Sweltzer Creek, not exactly to scale.

3₃ coho would probably usually be classed as jacks although they were somewhat larger than the 2₂'s. A count of the 3₃'s was obtained in 1927, when they had been marked by removal of the ventral fins.

Table I gives a general picture of what entered Sweltzer Creek in the three years the lower fences were used, and Table II shows the seasonal distribution of the 1933 run. The runs of the other four species of salmon are included to show the relative times of migration. Unfortunately no. 1 fence was not tended long enough in 1933 to obtain a complete count of the cohoes, which run later than the other species. The 1933 operation ended December 23. In 1934 it was prolonged to January 3, and the additional eleven days increased the coho count by only 3.5 per cent. Extrapolation is uncertain, but the 1934 count is probably

TABLE I. Adult salmon counted at fence 1, excluding "jack" coho. Counts marked with an asterisk are incomplete; that is, the count was discontinued while fish were still arriving. The 1932 sockeye count is 92 per cent complete, and the chum count probably about the same.

Year	Period	Coho		Chum		
		Male	Female	Male	Female	Not sexed
1932	Sep 20-Nov 13	Not counted		3,920*	4,044*	9,485*
1933	Sep 19-Dec 23	1,274*	1,366*	1,766	2,296	.....
1934	Sep 30-Jan 3	382*	734*	3,026	7,260	.....

Year	Period	Pink		Sockeye		Spring	
		Male	Female	Male	Female	Male	Female
1932	Sep 20-Nov 13	0	0	610*	1,173*	3	0
1933	Sep 19-Dec 23	522	603	1,568	1,854	2	1
1934	Sep 30-Jan 3	0	0	4,046	18,980	4	0

TABLE II. Arrival of adult salmon at fence 1 in 1933, by five-day periods. "Jack" coho are not included.

	Coho		Chum		Pink		Sockeye		Spring	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Sep 21-25					3	3				
26-30		1			33	15	11	4		
Oct 1-5	1	3	1	1	32	22	12	10		
6-10		1	10	6	57	29	47	33		
11-15	2	1	21	4	105	60	37	35		
16-20	17	17	86	39	140	148	227	143		
21-25	65	107	233	138	75	184	352	303		1
26-31	32	51	193	220	35	88	85	92		
31-4	63	82	392	454	26	42	131	124	1	
Nov 5-9	34	28	191	303	15	9	51	70		
10-14	33	52	217	395	1	1	64	168		
15-19	26	24	142	314		1	127	238		
20-24	181	198	115	156		1	374	446		
25-29	90	109	62	126			20	74		
30-4	61	69	63	72			19	68	1	
Dec 5-9	325	273	36	52			2	40		
10-14	243	239	4	14			0	2		
15-19	38	65		2			8	2		
20-24	33	46					1	2		
TOTAL	1,274	1,366	1,766	2,296	522	603	1,568	1,854	2	1

about 90 per cent complete, and the 1933 count perhaps 85 per cent. Occasional living cohoes have been seen in the creek as late as March, and in one year even in early April.

Pink, chum and coho salmon spawn abundantly in Sweltzer Creek. The fraction which would naturally ascend as far as fence 6 is not known, because in years when a count was made at fence 1, fence 6 traps were closed until early November in order to permit the sockeye to ripen. Thus many arriving individuals of all species were held at or below fences 5 and 6, and some spawned and died there. This "handicap" was greatest for the earlier-running species, pinks and chums, and very few of the 1933 or 1934 run of these species were counted over fence 6 after it was put in operation (Table III). In 1935 there were no fish-cultural operations, and 320 pinks and 976 chums entered fence 6 and were put above it. Many of these may have spawned below the lake, but these species have also been observed in the lake and in its tributary Dumvill Creek. Coho were less affected by the delay in opening the upper fences, and in 1933 and 1934, 40 and 23 per cent respectively of the coho (other than jacks) that were *put over* fence 1 arrived at and were put over fence 6. In all years some part of these spawned in Sweltzer Creek between fence 6 and the lake; but a considerable number normally went on through the lake and spawned in Dumvill Creek, a spring-fed creek at its upper end, where they could readily be observed. They were *not* seen in Frost Creek, a stream normally larger but subject to drying out near its mouth; however no very extensive search was ever made. It is not known whether any coho spawned in the lake itself; nearly all of the sockeye did so.

TABLE III. Adult salmon put over fence 6 in four years, excluding coho "jacks".

Year	Period	Coho			Chum		Pink		Sockeye	
		Male	Female	Not sexed	Male	Female	Male	Female	Male	Female
1932	To Jan 17	574	709	272	Not counted		0	0	756	1,781
1933	Nov 7-Dec 27	504	485	..	33	46	A few		..	..
1934	Nov 12-Jan 5	108	140	..	32	39	0	0	..	..
1935	Oct 16-Jan 28	319	294	..	544	432	215	105	5,412	9,927

The seasonal arrival of salmon at fence 6 in 1935 is shown in Table IV. Its beginning is somewhat truncated by the fact that fish were allowed to accumulate until October 16. A few coho were still entering during the five-day period ending January 28, but obviously the run was substantially over by then. Table IV includes a partial segregation of jacks and older coho; the former were much more numerous, and became increasingly so toward the close of the season.

The available information on coho of all types put over fence 6 is given in columns 2-4 of Table V. Of all species of Pacific salmon, coho show the least external difference between male and female at maturity, and a small part of the large fish arriving at the fence were not yet mature enough to be certainly distinguished. Usually the uncertainty was resolved by guessing at the most probable sex, by those doing the work; hence the sex distributions of Table V and earlier tables should not be considered as exact. There are, however, no gross departures

TABLE IV. Arrival of salmon at fence 6 in 1935. Up to November 29 "jack" and large male coho were not segregated; an estimate for this period is 342 "jack" and 154 large, based on the ratio observed Nov. 30-Dec. 14.

Period	Coho				Chum		Pink		Sockeye	
	"Jack" male	Large male	Total male	Female	Male	Female	Male	Female	Male	Female
Oct 16-20			39	8	8	2	10	5	1,132	1,381
21-25			31	15	38	8	32	21	378	422
26-30			25	12	31	11	40	27	761	766
31-4			15	1	48	28	89	20	63	69
Nov 5-9			23	9	119	100	24	20	435	656
10-14			46	4	84	76	18	11	260	418
15-19			75	21	87	86	2	1	533	1,038
20-24			60	21	47	48			741	1,641
25-29			182	47	24	44			473	1,444
30-4	68	38	106	30	19	14			319	741
Dec 5-9	49	21	70	28	10	8			250	943
10-14	140	57	197	68	20	7			64	361
15-19	42	16	58	18	6	0			2	19
20-24	35	6	41	2	2	0			0	14
25-29	44	5	49	3	1	0			1	12
30-3	67	6	73	4					0	2
Jan 4-8	99	14	113	3						
9-13	0	0	0	0						
14-18	16	0	16	0						
19-23	18	1	19	0						
24-28	4	1	5	0						
TOTALS	582	165	1,243	294	544	432	215	105	5,412	9,927

TABLE V. Summary of coho spawnings and their known products. Blank entries indicate absence of information.

Year of spawning	Adults put over fence 6				Migrants counted at fence 7			Caught in lake	
	Age-II males	Older males	Females	Eggs available for deposition	Fry	Yearlings	2-year	Age I	Age II
1924							72		
1925		526	619	1,420,000		1512	106		
1926		586	463	1,060,000			65 ^a		
1927		900	813	1,870,000		2200 ^a	40		
1928		^a	^a		16,000 ^a	176			
1929		248 ^b	278 ^b	640,000	28,923		6+		8
1930		557	358	820,000		1274		1	
1931		257	257	590,000	40,000 ^b				
1932		752 ^c	883 ^c	2,030,000				10	13
1933		504	485	1,120,000				31	183
1934		108 ^d	140 ^d	320,000 ^d			0?	57	18
1935	924 ^e	319 ^e	294	680,000		1852	6+	266	167
1936	0	0	0	1,063,000 ^f	5,008	3251	16+	0	359
1937	0	0	0	0	0	492	16	0	4
1938	364	279	238	548,000	24,497	3687	157	20	645
1939					17,959	3558		2	305
1940	364	91	68	156,000	2,509	351		0	
1941	326	281	342	787,000	17,844				
1942	239	276	292	671,000					
1943	255	70	57	131,000					

^a About 350 female coho were spawned artificially in 1928, and the records are not clear concerning how many were put into the lake.

^b An additional 113 females and some males were spawned artificially.

^c 272 unsexed fish are divided equally between male and female.

^d Most of these were stopped by fence 7 which was closed up to Jan. 25.

^e The ratio of age-II to age-III males is partly estimated (see Table IV).

^f Eyed eggs planted from the hatchery.

^g Partly estimated.

^h 35,826 were actually counted, but the count was discontinued near the end of the run.

from an even sex ratio, and no consistent tendency for either sex to predominate among the large fish. The jack coho examined have always been of the male sex, and all jacks are recorded as males.

The number of adult coho shown in Table V is the number *put over* fence 6. In years when sockeye salmon were merely being counted at the fence all salmon were dipped over every day, and the record of coho handled may be considered as practically the total number arriving. This was true in 1925, 1927, 1930 and 1938-43. Sockeye were stripped for artificial propagation in 1926, 1928, 1929, 1931, 1932, 1933 and 1934, and in these years the earlier coho were prevented from entering the lake. In 1934, contrary to usual custom, the screen fence was kept closed through the autumn and up to January 25, 1935, so that very few coho of the small run of that year ascended to spawn in Sweltzer Creek above the screen fence, or in the lake or its tributaries. In 1935 the migration was unobstructed to the end of December, but with the new year some of the fish were removed from the run by fish-cultural operations; probably the bulk of the run was already in the lake before this began. In both 1936 and 1937 no adult coho at all were put over fence 6. However some of the 1936 fish were spawned artificially, and the following spring 1,063,000 eyed eggs were planted in two streams tributary to the lake. No eggs of the 1937 spawning were planted, so that no young of that year's anadromous coho run reached the lake from its tributary streams. However some young fingerlings could have entered from Sweltzer Creek after June, 1938, when the screen fence was lifted.

In the years of record, the number of jack 2_2 coho counted at fence 6 is always greater than the number of male 3_2 coho of the same year-class recovered the following year. In view of this it is somewhat surprising that there is not a consistent excess of 3_2 females over 3_2 males, such as has been observed in a run of California coho (Murphy, 1952). The removal of the jacks must disturb the original sex ratio of any year-class, which ratio is probably fairly close to 50:50 to judge from experience elsewhere (Robertson, 1951). The problem cannot be solved from data at hand, but it is possible that the coho taken at fence 6 do not accurately represent the Sweltzer Creek population as a whole. That is, this sampling was done near the head of the creek and it might be that jacks tend to migrate farther upstream than the larger fish. Similarly the sex ratio of age-III coho at fence 6 might not reflect that of the whole run entering the creek.

EGG PRODUCTION. The only information on eggs produced by the Sweltzer Creek coho comes from the season 1936. In that year Superintendent A. Robertson of the Cultus Lake hatchery obtained an average of 2,300 eggs per female, using the "incision" method of spawning which removes practically all eggs from the fish. This number is used to calculate potential egg deposition above fence 6 for all of the years included in Table V. Wickett (1951) gives average egg counts from 2,100 to 2,662 for five years' observations at Nile Creek.

DOWNSTREAM-MIGRATING COHO

Young salmon leaving Cultus Lake in spring were stopped by a screen fence installed primarily to count migrating sockeye (Foerster, 1936a). In some years counts of other species of salmon were obtained also. The coho counted would

include not only those which had been living in the lake, but also coho from the short stretch of Sweltzer Creek between the screen fence and the lake. Coho left the lake at three different ages, all of which were readily separable on the basis of size. The available counts are given in Table V.

FRY. Recently-emerged coho fry appeared at the screen fence in moderate numbers, varying from 15,000 to 40,000 in normal years. In typical seasons like 1940 (Table VI) the principal migration extended over a rather long period of time, from March to mid-May, followed by a much smaller mode toward the end of May or in early June.

TABLE VI. Downstream migrations of coho, chum and pink salmon fry and coho yearlings in 1940, summarized by five-day periods. The fence was tended Feb. 5-June 8.

Date	Coho yearling	Coho fry	Chum fry	Pink fry
Feb 6-9	19			
10-14	16			
15-19	17			
20-24	19			
25-29	2		17	
Mar 1-5	6	47	10	24
6-10	6	47		23
11-15	0	30		8
16-20	2	34		7
21-25	5	104		451
26-30	3	1,872	32	2,762
31-4	3	1,765	142	2,111
Apr 5-9	0	4,079	2,947	4,255
10-14	6	2,603	548	3,712
15-19	25	1,353	407	1,831
20-24	17	1,871	2,572	655
25-29	28	1,908	1,284	53
30-4	162	1,389	34	19
May 5-9	189	1,469	685	8
10-14	443	197	385	1
15-19	373	3	177	
20-24	447	78	74	
25-29	895	58	6,691	
30-3	625	35	1,916	
Jun 4-8	223	47	633	
TOTAL	3,531	18,989	18,599	15,920

From the start of the Cultus Lake work, there was evidence that the fry of all species of salmon which were counted at the screen fence came largely from redds in Sweltzer Creek between the fence and the lake (Foerster, 1929, p. 62). An opportunity to test this proposition for coho was presented by the 1936 year-class, when there was no spawning in that stretch of the creek and all coho fry at the fence came from eyed eggs planted in creeks above the lake. The ratio of fry to potential egg deposition for all the available years is as follows:

<i>Year of spawning</i>	<i>Fry/eggs</i> %
1929	4.5
1931	6.8
1936	0.47
1938	4.5
1940	1.6
1941	2.3

The ratio of fry to eggs in 1936 was much the lowest on record, only 13 per cent of the geometric mean of the other years, in spite of the fact that the latter ratios are based on eggs *in females*, hence still subject to the vicissitudes of spawning and development. Even more striking is the fact that the coho fry of the 1936 brood did not appear at the screen fence until well on in May, 1937, and their principal mode was about June 12—at the time of the late “rump” migrations of other years (Figure 2). There is also in 1937 a small earlier, but still late, mode about May 15; the two modes may represent fry from the two different creeks into which the eggs were planted. We may conclude that in normal years fry which come from the lake are considerably less than 13 per cent of the total fry migration, possibly of the order of 5 per cent; and they are probably the latest group of fry to arrive.

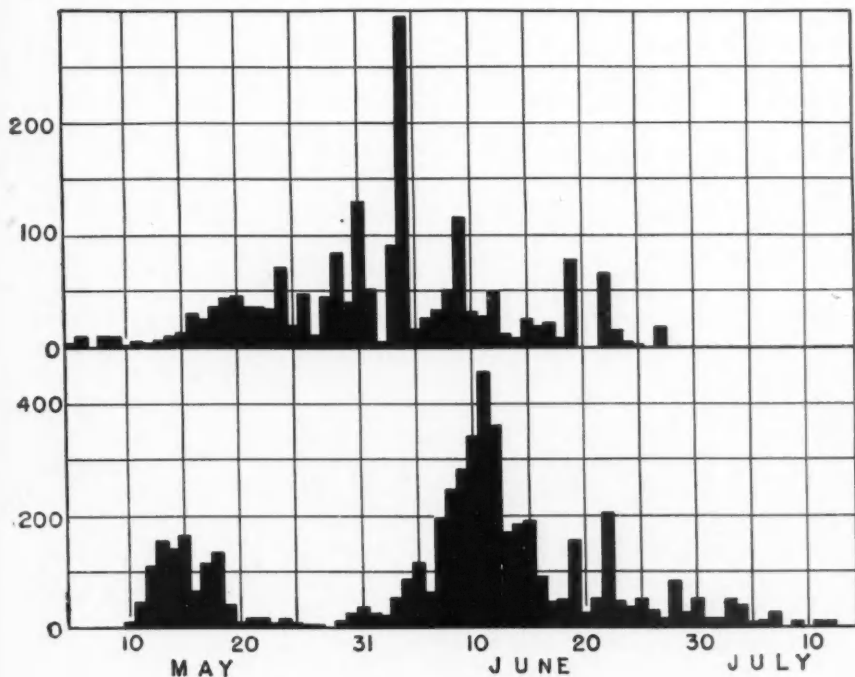


FIGURE 2. Daily catches of downstream-migrating coho in fence 7 during 1937. Above: yearlings (age I). Below: fry (age 0).

The number of coho which spawned in Sweltzer Creek above fence 6 can be estimated only approximately. Observation indicated something of the order of two or three dozen pairs, but no careful enumeration was ever attempted. As suggested above, about 95 per cent of the fry counted at fence 7 (column 6 of Table V) are presumed to be from spawners in Sweltzer Creek between fence 7 and the lake. If they are credited to females at the rate of 1,150 per female (one-half of their eggs surviving to fry), up to 33 females are required, the average for normal years being 20. A few pairs spawning between fences 6 and 7 must be added to these, but it appears that the number of coho which spawned in Sweltzer Creek above fence 6 was small in relation to the number which went on into or through the lake.

YEARLING SMOLTS. Yearling (age-I) coho were only moderately common at the screen fence (Table V). Their average size was of the order of 110 or 120 mm., somewhat larger than sockeye smolts of the same age. The longest screen-fence record available is that of 1940 (Table VI). It shows first a limited amount of movement throughout February, March and April, which is probably the normal wandering of stream-dwelling fish, and might well have been matched by a similar upstream wandering if the latter had not been prevented by the fence. A concerted downstream migration usually came in late May and early June, varying a little from year to year, but always with its peak about 10 days later than that of the sockeye smolt migration. The 1940 migration (Table VI) is unfortunately cut off at June 8; that of 1937 is complete toward the end but lacks the period prior to May 1 (Figure 2).

Although most of the yearling smolts are presumed to be the progeny of coho which entered the lake and spawned above it or in it, there are two other possibilities. A part of the progeny of coho spawning above the screen fence but below the lake may be represented. So may some progeny of coho spawned farther down Sweltzer Creek, which could have wandered upstream above the screen fence after the latter was lifted (usually in late June or July). Evidence for this latter effect is available from the spawning of 1937. No adult coho were released above fence 6 that year, and consequently no fry appeared at the screen fence in 1938. However 492 yearling coho entered the fence in 1939, which could only be wanderers of the type just described.

In Table VII the yield of yearlings is computed as a percentage of eggs available. From the previous paragraph it is evident that the figures given in column 7

TABLE VII. Production of smolts related to eggs available and to number of female spawners.

Year of spawning	Yearling production	
	Percentage of eggs	Per female spawner
1925 (natural spawning)	0.11	2.5
1927 " "	0.12	2.8
1930 " "	0.16	3.7
1935 " "	0.27	6.2
1936 (eyed eggs planted)	0.31	..
1938 (natural spawning)	0.67	15.4
1940 " "	0.22	5.1

of Table V represent a maximum estimate of the yearlings produced above the screen fence by the eggs in females put over fence 6, and hence the figures of Table VII are a little too large. However their most interesting feature is that all are very low. The average survival from natural spawning is 0.13 per cent for the three years in the period 1925-30, that is, prior to control of piscivorous fishes in the lake (Foerster & Ricker, 1941); this is only three smolts per female. After 1934, production of smolts became somewhat better; it had a geometric mean value of 0.33 per cent, or eight smolts per female, under the artificial condition of a reduced predator population.

TWO-YEAR-OLD MIGRANTS. Production of two-year-old coho migrants is small compared to the number of yearlings, and very small absolutely. The greatest number recorded was 157 or 0.029 per cent of eggs available, while as few as six have been obtained from a normal seeding (Table V).

The size of the two-year-old migrants taken varied considerably from year to year, but measurements were made in only a few years. In 1932 six individuals taken at fence 7, March 25-April 11, measured 252, 268, 252, 259, 273 and 264 mm., in order of capture, the mean being 261 mm. In 1939 sixteen specimens were taken May 27-June 5, and it is possible to compare them in size with the coho of the same age caught in the lake at about the same time (Figure 3). The migrants show no difference from the net-caught fish in mean length or in variability in length. They included six males and ten females. In May of 1940 four of the migrating coho taken at fence 7 were killed. All were males, measuring 230, 360, 365 and 455 mm. The last is by far the largest coho known to have left the lake; it weighed 1,000 grams.

SURVIVAL FROM SMOLT TO ADULT. MARKING EXPERIMENTS.

In the spring of 1927 migrating coho were marked by clipping off the two pelvic fins. A total of 1,512 yearling and 72 two-year-old smolts were so treated.

Nineteen of the 72 large ones, or 26 per cent, returned the same year after five or six months' absence, thus completing their life cycle in the usual three years, as 3₃ fish. Examination of their scales showed a few widely-spaced (sea-type) circuli.

In 1928 there were 122 marked coho counted over fence 6. A few of these might have been additional survivors of the 72 two-year-old smolts, maturing as 4₃'s; however Pritchard found less than 1 per cent 4₃'s among commercial-sized coho, so that these can be ignored without appreciable inaccuracy. Considering the 122 marked adults of 1928 to be survivors of the 1,512 yearlings of 1927, returning in their normal cycle year as 3₂'s, their survival rate was $122/1,512 = 8.1$ per cent.

Although this percentage is rather high in comparison with results elsewhere, it may be too low to be representative, for several reasons. For one thing, there is no assurance that all of the marked smolts returned as far as fence 6; some may have spawned in the creek below it. In addition, it has been shown (Foerster, 1936b) that removal of fins is a rather serious handicap to yearling *sockeye* salmon, reducing their rate of return to 38 per cent of normal. Coho yearlings,

being larger, are probably less seriously affected by this extra mortality, but can scarcely be untouched; hence 8.1 per cent is too low to represent the survival of normal yearlings to the age-III stage. Finally, considering the usual abundance of "jacks" at Cultus, it is probable that some part of the 1,512 marked yearlings matured as "jacks" and slipped through unobserved in 1927.

In the fall of 1929 adult coho at fence 6 were examined for marks and two were taken with the ventral fins removed; these were probably 4₂ fish from the 1927 marking. However there is some possibility they may have been survivors of yearlings marked in 1928 by mistake. No coho were deliberately marked that year, but sockeye were marked by removal of both ventral fins and half the dorsal fin. A few coho might conceivably have been included by accident and the distinguishing half-dorsal tended to regenerate and is easily overlooked.

MAINTENANCE OF THE LAKE POPULATION

Although the percentage return of coho smolts to the lake seems fairly high, it is not high enough to compensate for the very low rate of smolt production shown in Table VII. Hence it appears that anadromous coho would not maintain themselves in the lake if they were cut off from the Sweltzer Creek population, immediately at least. Of the three factors mentioned above as tending to make the observed 8.1 per cent rate of return too small, possible marking mortality is the only *artificial* factor which reduces the return of females to the lake. If the 8 per cent were even doubled to allow for this, it still provides very poor returns when combined with the smolt yields of Table VII. On this basis the 1925-30 average is 0.25 daughter spawners produced per adult female, and the 1935-40 average is 0.6, the first figure being representative of natural conditions. Obviously the return is not sufficient to maintain the run indefinitely. Thus it is not surprising to find that in some years—perhaps in all years—the lake receives a large contingent of fish which were raised elsewhere. In 1928 only 122 out of 700 or more adult coho reaching fence 6 were survivors of the smolts marked at the screen fence in 1926. The figure 122 may be somewhat too small for reasons just explained, but it remains small even after any reasonable adjustment, so that even under normal conditions the majority of the adult coho entering the lake in 1926 would not have come from the lake originally. Similar relations appear in other year-classes of Table V; for example, the 1,274 smolts of the 1930 year-class could not possibly have produced the 989 large adults of 1933! It is evidently customary to have enter the lake a large number of adult fish which were raised in Sweltzer Creek, or possibly even farther afield. Conversely, while lake-bred fish may contribute something to the creek's population, this contribution cannot be very large.

RESIDUAL COHO

OCCURRENCE AND ABUNDANCE

There exist in Cultus Lake each year considerable numbers of coho which do not go to sea. Evidence to be presented suggests that these are largely offspring of the anadromous fish. Non-migrating salmon which are the offspring of ana-

dromous parents have been called "residual" salmon (Ricker, 1938). Residual coho are frequently caught by anglers in the lake, and were also taken in numbers by gill-nets used for control of predacious fish (Foerster and Ricker, 1941). They were caught principally in the autumn of their second year of life and in the spring and early summer of their third year. In late summer and autumn of their third year they suddenly become scarce in the nets, but a few were taken up to and into the spawning season. After June in any year the two-year-old coho taken in the lake are certain to be of the non-anadromous type, and in fact their gonads show signs of approaching maturity. One-year-old coho taken after June in any year, and two-year-olds from January to June of the following year, are largely of the non-anadromous type, because relatively few two-year-olds go to sea.

The total number and age of non-migrating coho obtained in gill-nets, from spawnings of recent years, is indicated in Table V. The number caught of course depends partly on the amount of fishing. This has been described for the years 1932-38 by Foerster and Ricker (1941). Briefly, from 1932 to 1934 only occasional experimental sets were made, which caught 12 coho in all; a few taken by angling brings the total examined up to 19. Beginning in June, 1935, intensive netting was carried on almost continuously, up to June, 1938. From 1939 to 1942 intensive netting was carried on during the first half of the year only, stopping some time in late May or June. Nets of 11 sizes were used, from $1\frac{1}{2}$ to 5 inches (38 to 127 mm.) stretched mesh, but after 1935 the meshes from 2 to 4 inches (51 to 101 mm.) were most frequently set.

The January-June fishing takes age-II coho almost wholly, and coho of seven spawnings have been actively fished at that period of their life. The numbers taken are summarized below:

<i>Year of spawning</i>	<i>Spring catch of age-II residuals</i>	<i>Year caught</i>
1933	178	1936
1934	17	1937
1935	169	1938
1936	359	1939
1937	4	1940
1938	645	1941
1939	305	1942

There are obviously two spawnings which produced very few age-II coho in the lake: 1934 and 1937. These two are also years when there was serious interference with the entry of adult coho to the lake (Table V). In the 1934-35 season coho could not pass the screen fence until January 25, and in 1937-38 no anadromous coho at all were permitted to enter the lake. It is evident that the occurrence in the lake of appreciable numbers of age-II coho of any given year-class depends upon the presence of parent anadromous coho in the appropriate year. Hence the great majority of non-anadromous coho in the lake must in fact be of the "residual" type—non-anadromous progeny of anadromous parents.

A similar conclusion can be reached by comparing the number of residual coho in the schedule above with the smolts of the same year-class (column 7 of Table V). Data for five years are available, the year-classes 1935-39. The co-

efficient of correlation between residuals and smolts is 0.87, a result which lies at the 95 per cent confidence level. This indication of parallel fluctuation in abundance of smolts and residuals is, of course, what would be expected if they are two parts of a common stock.

The average size of the ratio of smolts to residuals is not accurately known, but an estimate of its order of magnitude is possible. Combining the years 1935-39, there are 12,840 yearling smolts and 1,482 spring-caught age-II residuals. Very approximate estimates of the annual rate of exploitation of other fishes in the lake, by the full-year netting program of 1936-37, work out between 10 and 40 per cent. The half-year effort on coho might therefore yield a 5 to 20 per cent catch, so that the aggregate of populations from which the five-year catch of residuals came may lie between 29,600 and 7,400, estimated as of January 1. They had, however, suffered some mortality in the period between January and the beginning of the previous June. Ricker and Foerster (1948) estimated the June-through-May survival of yearling sockeye during these years as 10 per cent, corresponding to an instantaneous mortality rate of 2.30. If the "force of mortality" is equally distributed between the two parts of the year, the June-through-December rate would be seven-twelfths of this, or 1.34. However, yearling coho are considerably larger than sockeye in June and become very much larger as the summer progresses; hence they are likely to be less subject to predation, and accordingly their half-year mortality is taken to be of the order of only one-half to one-third of the rate for sockeye; this is 0.67 to 0.45 on an instantaneous basis, corresponding to survival rate of 51-64 per cent. Combining these very crude limits with the equally crude limits of January populations yields a figure for the combined June populations of age-I residual coho which lies between the extremes of 12,000 and 58,000. Comparing this with 12,840 known smolts, we conclude that the average number of non-migrant yearlings is likely to be from as great as, to four times as great as, the number of migrants.

SIZE. Young coho can be taken in Cultus Lake during their first summer of life by beach seining. Considerable seining was done in 1936 and 1937; 1,042 age-0 fingerlings of the year-class of 1935 and about 2,000 of that of 1936 were caught, most of them being released alive. These of course were still potentially migratory. During their first winter and up to May or June of their second year of life coho were not taken in the lake, but from that time onward they appeared regularly in gill-nets set either on bottom, or floating near shore. The wide range of net sizes used yielded samples of all sizes of coho larger than about 150 mm., and from 1935 onward it has been possible to follow their growth in the lake month by month. Figure 3 shows the length distribution of the age-II residuals of the year-class 1936, caught in 1939. Figure 4 shows a fairly complete history of the year-classes of 1933 and 1934, and less complete data for those of 1932 and 1935.

Characteristics of the length frequency distributions of the older lake coho include a rather large variability and a tendency toward asymmetry—the smaller end of the distribution being attenuate (Figures 3 and 4). Either or both may be partly the result of the protracted spawning season of the species, and the variety

of habitats available for the young. For example, the unusually small individuals at age II might be fish which spent a year in cold Dumvill Creek, instead of moving down to the lake as fry or early fingerlings.

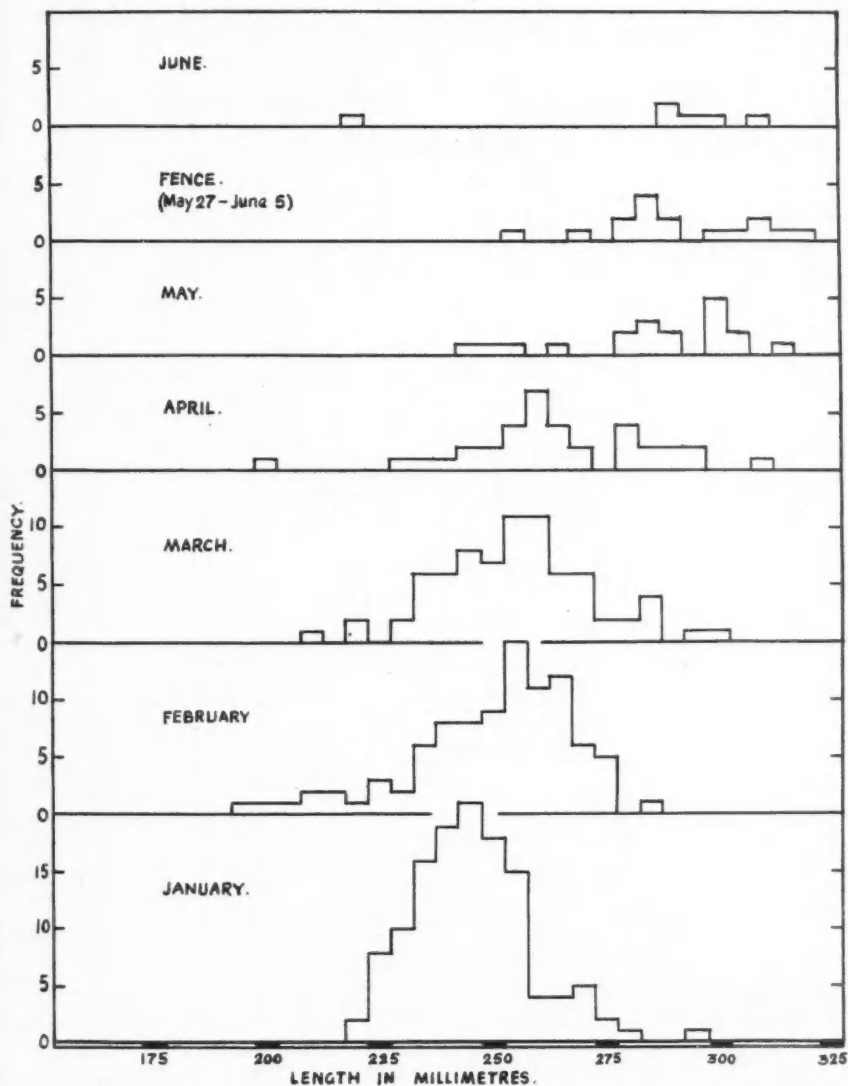


FIGURE 3. Frequency distribution of fork length of age-II residual coho caught in Cultus Lake in successive months of 1939, and that of 2-year-old downstream migrants taken at fence 7 in the same year.

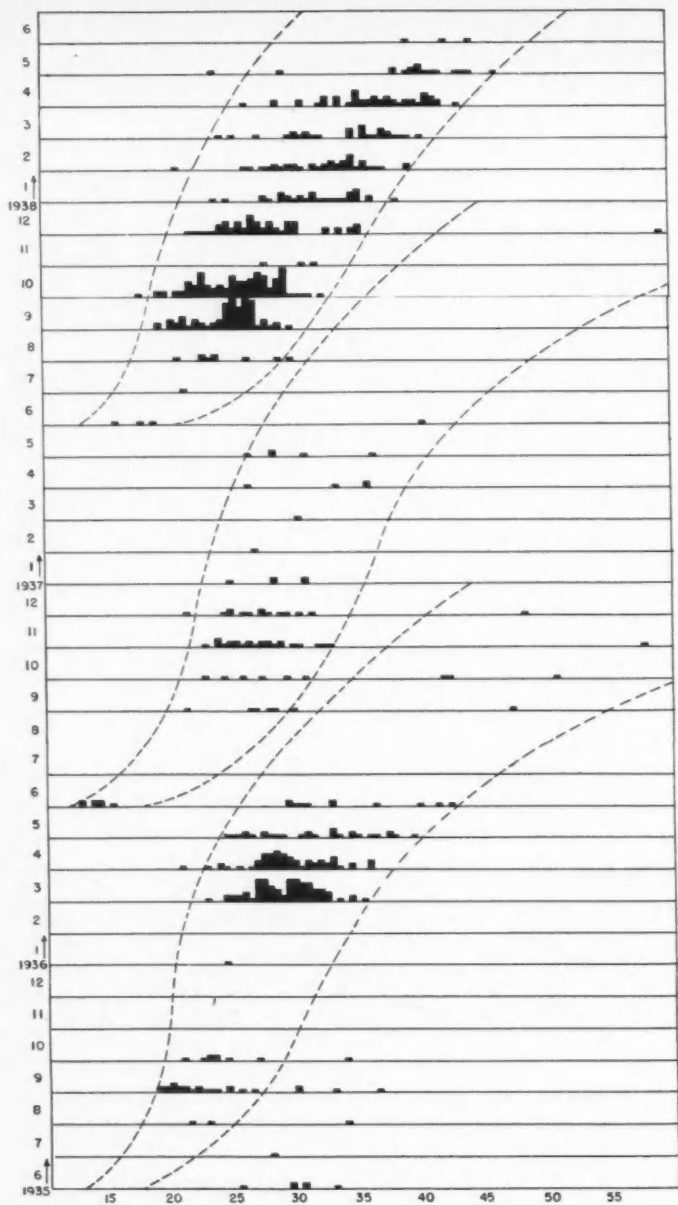


FIGURE 4. Frequency distributions of coho caught in Cultus Lake from June, 1935, to June, 1938. The curved dotted lines enclose most of the individuals belonging respectively to the year-classes 1933, 1934 and 1935 (from below upward). Abscissa: fork length in centimeters.

Mature and maturing residual coho are of smaller average size than their anadromous relatives, and on the whole they are less brightly coloured. A few residual coho were taken that were as large and as brightly coloured as are some anadromous coho. Such were first seen in the autumn of 1932: a female 465 mm. long taken late in November would probably have been considered an anadromous fish but for the fact that no anadromous coho had yet been put above fence 6. Closer inspection showed that this specimen had *Salmincola* on its gills, and this ubiquitous freshwater copepod parasite has occurred on all the larger non-anadromous salmon, both coho and sockeye, taken in Cultus Lake, as well as on many of the small ones. Since *Salmincola* do not occur on coho migrating from the sea, the presence of this parasite provides a decisive test of the provenience of large coho, something which is needed when both anadromous and freshwater types are in the lake. The largest residual cohoes taken are listed below:

Nov. 22, 1932	female	465 mm., 1280 g.	Nov. 12, 1936	male	580 mm., 2310 g.
Sep. 25, 1936	"	477 mm., 1630 g.	Dec. 17, 1936	"	487 mm., 1540 g.
Oct. 16, 1936	male	512 mm., 2000 g.	Dec. 20, 1937	"	595 mm., 2400 g.

However these fish are all less than the *average* size for anadromous coho, which is about 610 mm.

The relation of weight to length of residual coho is shown in Figure 5, based upon fish caught in 1932-38. With a few exceptions, weights were taken to the nearest tenth of a pound only.

The average fork length and standard deviation in length of the coho taken in Cultus Lake is presented in Tables VIII and IX, the sexes being separated

TABLE VIII. Number, mean length in mm. and standard deviation in length of lake-caught coho in the second year of life.

Year-class	Year	Month	Males			Females		
			No.	Length	s.d.	No.	Length	s.d.
1930	1932	Sept	1	284				
1932	1934	July	2	165	4.2	6	165	3.8
		Aug	1	169				
1933	1935	Aug	2	222	9.2			
		Sept	13	215	23.4	7	220	22.5
		Oct	7	235	18.8	1	235	
1934	1936	June	7 ^b	141	7.6	b		
		Sept	5	280	13.7			
		Oct	5	71	37.7	2	237	9.9
		Nov	15	78	31.8	10	266	21.4
		Dec	8	272	33.0	5	267	19.5
1935	1937	July	1	215				
		Aug	7	252	33.6	2	238	3.4
		Sept	49	250	24.7	22	251	23.0
			3 ^a	265	5.0			
		Oct	49	256	29.3	48	258	31.1
			4 ^a	273	51.0			
		Nov	2	298	17.0	2	301	26.9
		Dec	22	292	33.1	36	275	34.5

a Maturing during the year of capture.

b The sex of these 7 was not determined.

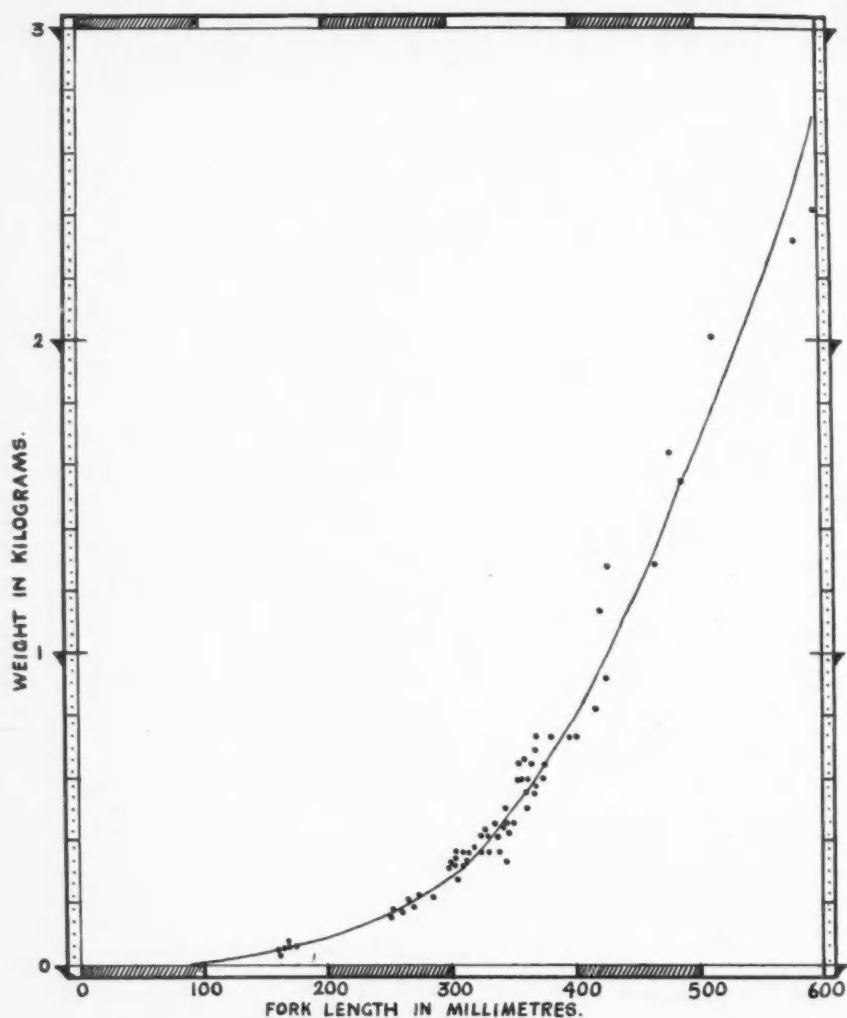


FIGURE 5. Relation of weight to length of residual cohoes from Cultus Lake.

as far as data are available. The coho which first appear in the nets, in June of their second year, are 130–160 mm. long; possibly because of net selection, they are somewhat larger than the smolts which have just gone to sea. Their growth during the ensuing summer is rapid, and by October they usually average close to 250 mm. Subsequent growth varies a good deal from year to year. April of the third year of life is the latest time for which good samples are available in

TABLE IX. Number, mean length in mm. and standard deviation in length of coho in the third year of life.

Year-class	Year	Month	Males			Females		
			No.	Length	s.d.	No.	Length	s.d.
1929	1932	March	2	248	20.5	3	270	28.0
		Sept	1	368				
		Nov	1	345		1	465	
1932	1935	June	4	291	18.3	2	312	25.0
		July	1	285				
		Aug				1	340	
		Sept	3	323	38.1	1	330	
		Oct				1	340	
1933	1936	Jan	1	245				
		March	35	296	19.8	43	289	26.7
		April	25	290	37.1	35	299	24.8
		May	17	322	48.6	11	302	36.5
		June	5	357	53.7	6	327	50.3
		Sept				1	477	
		Oct	2	470	60.1	1	420	
		Nov	1	580				
		Dec	1	487				
1934	1937	Jan	4	289	28.4	1	285	
		Feb	1	270				
		March	1	305				
		April	3	320	49.2	1	360	
		May	3	306	53.6	2	298	17.6
		June				1	400	
		Dec	1	595				
1935	1938	Jan	12	310	40.2	19	327	29.2
		Feb	16	333	30.0	24	335	33.6
		March	14	341	41.5	15	353	36.0
		April	21	370	36.2	27	368	35.7
		May	9	397	61.2	8	411	17.1
		June	1	395		2	435	14.1
1936	1939	Jan	53	241	11.7	72	243	14.8
		Feb	46	248	17.0	45	247	19.6
		March	40	252	16.5	35	253	17.9
		April	22	264	18.9	15	259	24.0
		May	14	280	21.5	17	288	14.2
		June	7	287	32.6	3	297	15.2
1937	1940	Feb	0	...	....	1	270	....
		March	1	290	....	0	...	....
		April	0	...	....	1	230	....
		June	0	...	....	1	279	....
1938	1941	Jan	69	338	48.6	84	341	35.5
		Feb	96	345	42.8	146	348	33.4
		March	52	361	42.0	55	355	34.2
		April	34	386	42.5	24	379	35.9
		May	32	394	51.3	53	389	37.4
1939	1942	Jan	12	297	34.2	17	281	28.7
		Feb	12	307	38.7	7	327	29.8
		March	34	329	25.4	52	319	27.8
		April	51	329	24.6	59	325	26.4
		May	15	347	33.2	25	349	19.1
		June	8	360	20.0	13	343	45.7

most years, and a comparison of average size (sexes combined) is shown in column 3 of Table X. The cube of this length is given in column 4, this being a figure fairly closely related to the average weight of the fish in successive years. The latter may be compared with the number of sockeye salmon which left the lake in the spring of each of the years in question (column 5), because young sockeye are the principal food of lake coho (Ricker, 1941). With so few pairs of values a significant relationship would scarcely be expected (Figure 6). Even so, the apparent correlation of 0.56 is rather small, and would suggest that only 31 per cent of the variation in size of the coho was dependent upon the size of the sockeye population.

TABLE X. Mean size of age-II coho in April (March to May for the 1934 year-class), compared with abundance of sockeye and air temperature.

Year-class	Year	Mean length	Length ³ ÷ 10 ³	No. of sockeye migrants	Mean temp. Dec-Mar.
		mm.		thousands	° F.
1933	1936	295	257	498	39.0
1934	1937	314	310	3,095	35.8
1935	1938	369	504	647	39.5
1936	1939	262	180	217	39.0
1938	1941	383	563	3,968	45.2
1939	1942	327	350	1,778	41.2

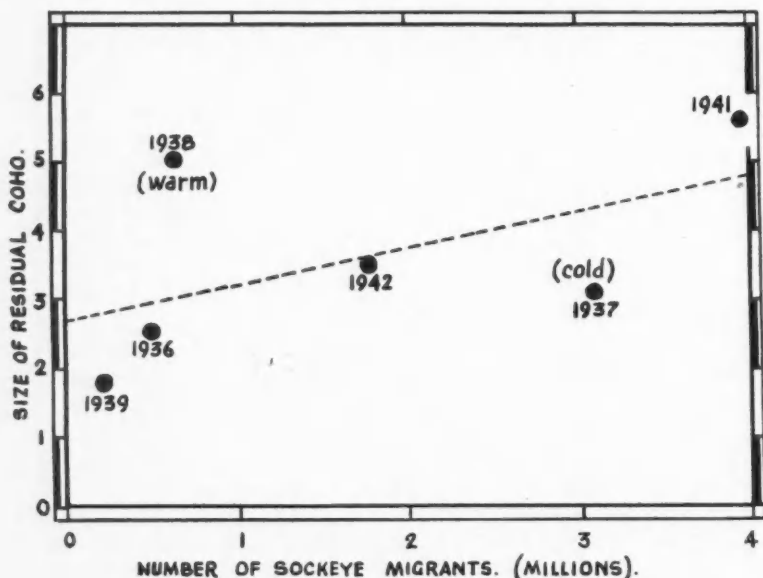


FIGURE 6. Relation between number of migrant sockeye taken March-June in each of six years, and the cube of the average length of residual coho taken in April of the same year.

The temperature of the lake is another factor which might influence rate of growth, particularly during the cooler months when it is nearly uniform from top to bottom; and rather pronounced temperature differences did occur during the period under discussion. Winter and early spring were unusually cold in 1937 and unusually mild in 1938; and the coho sizes in these two years deviate sharply, in the expected direction, from the trend line established by the sockeye abundance (Figure 6). An attempt was made to take account of temperature quantitatively by considering the average December-to-March air temperature at Agassiz, 20 miles north-northeast of Cultus Lake (B.C. Department of Agriculture, 1935-43). (Foerster, 1937, had found a significant correlation of 0.82 between the temperature of the Cultus Lake outlet and the local air temperature in the period January-March, over eight years.) The correlation of coho size with the winter Agassiz temperature was 0.69, which is perhaps suggestive. The multiple correlation of coho size with air temperature *and* sockeye population was 0.74. All these are non-significant results statistically, so would require more years' data to confirm them.

SEX AND GROWTH

The numbers of each sex found in samples of residual cohoes are shown in Tables VIII and IX. Significant departures from a 50:50 sex ratio appear in a number of instances, but their interpretation is not easy. Catches for individual days show even greater variability, so possibly the effect stems from a slightly different ecological distribution of the two sexes, or from some tendency for fish of like sex to associate together. The year-class of 1934 shows superiority of males in 11 out of the 12 months in which it appeared, the total count being 33 males and 17 females. It is the consistency rather than the final 2:1 ratio which is significant; deviations as great as the latter occur in single months of other years, but without falling into any pattern. Apart from the 1934 year-class, there is a small but distinct excess of females in January-June of the third year of life. The grand total for that period is 747 males and 917 females, or 44.8 per cent males. (Inclusion of the 1934 year-class increases this only slightly, to 45.1 per cent.

The maturing age-I specimens have been exclusively male. Unfortunately, they were not always distinguished from non-maturing ones in the records, so their relative abundance is uncertain. In September and October of 1937 seven specimens were recorded as definitely maturing, as against 98 that had no such entry and were probably all non-maturing. The maturing ones average somewhat larger than the others (Table VIII), but they included one really small individual 195 mm. in length. The records give some indication that in 1936 maturing age-I males may have exceeded non-maturing ones, but the data concerning maturity may possibly be incomplete.

The mean size of specimens of each sex is shown in Tables VIII and IX. There are no consistent differences in size of the two sexes, and the samples were large enough, in some years, to have revealed any dissimilarity worth considering. The one difference between the sexes that does show up occurs only among the

age-II fish of 1941, among whom the females are consistently *less variable* in length than the males—the standard deviations were about 35 mm. for males and 45 mm. for females. The frequency distributions in 1941 were unusually attenuate toward the lower end in both sexes, but especially among males, and this largely accounts for the difference in variability. The existence of this difference in 1941 and not in other years may be related to the fact that total average size achieved in 1941 was considerably greater than in any other year.

In the autumn of their third year coho were only rarely taken. This was partly because in some years netting was curtailed on account of the adult sockeye in the lake. In 1936, however, netting was pursued intensively throughout the autumn, but the number of age-II coho caught was only six, although the same brood had been taken abundantly in the spring. The total autumn-caught third-year coho for all years is ten males and six females. These tended to be very large in size as compared with those caught in spring (Table IX, Figure 4), almost suggesting selective mortality of all but the largest members of each year-class.

DISCUSSION

COMPARISON OF COHO AND SOCKEYE

The differences between anadromous coho and sockeye salmon are well known, and the Cultus Lake and Sweltzer Creek runs are in no way peculiar. In the Fraser River system both species characteristically spend a year in fresh water (one and a half years from time of egg deposition); but whereas sockeye always spend this time in lakes, young coho are chiefly stream dwellers. Coho commonly mature at age III, but produce a variable number of age-II males (jacks) in different populations. Sockeye of the Fraser mature mostly at age IV but there are some age-III jacks and very rarely age-II jacks, both kinds being relatively much less common than coho jacks at Cultus Lake. Jack sockeye include a few females, which sex has not yet been identified among jack coho. In both species a few individuals spend two and a half years in fresh water before migrating and a few go to sea directly as fry. Also, in both species a few individuals mature at an older age than what is characteristic for the species.

Much less is known about the distribution and abundance of "residual" salmon. In addition to residual cohoes, Cultus Lake contains residual sockeye (Ricker, 1938) and it is worth while to compare this phase of the two species in detail.

AGE AT MATURITY. Coho residuals mature at the same age as anadromous coho customarily do: males at age II, males and females at age III. The relative abundance of the two ages of males is not well established for either anadromous or residual coho, but there is no suggestion that earlier maturity is characteristic of residuals.

Among sockeye, on the other hand, residuals tend to mature at an earlier age than do anadromous fish. Whereas most anadromous sockeye are age IV, the commonest age for residuals is III; IV's are much less common, and some II's have been taken—the latter being almost unknown among the anadromous sockeye.

SEX RATIO. Among cohoes the sex distributions of the residual and anadromous groups are very much alike. Individuals maturing at age II are always male, while among the age-III fish the two sexes are fairly evenly represented. At Cultus Lake females are slightly in excess among age-III residuals (at least as they are caught in nets), and this has not yet been confirmed for the anadromous population; however an excess of females is customary in a California anadromous coho population (Murphy, 1952).

The situation is quite different among residual sockeye, where females are scarce at ages III and IV, and absent among fish maturing at age II. The scarcity of females at age IV stands in sharp contrast to the anadromous population, which at Cultus Lake commonly has a considerable excess of females. The latter is apparently the result of selective fishing, since the sockeye smolts are very close to 50:50 in sex distribution (Foerster, MS).

RELATIVE ABUNDANCE OF RESIDUAL AND ANADROMOUS FISH. The facts just mentioned confirmed what was evident on other grounds, that sockeye residuals in most years constitute only a small fraction of the total sockeye production of Cultus Lake. For coho, we have crudely estimated residuals at time of migration to be from about as numerous, to several times as numerous, as are the smolts. A relatively large proportion of non-migrant coho is also suggested by the low production of coho smolts as computed on the basis of eggs in spawners. In three years of natural propagation prior to 1935, the geometric mean of the sockeye smolt productions was 1.55 per cent of eggs available; for coho during the same period it was only 0.13 per cent. Some part of this difference, and probably the larger part, is a result of greater diversion of coho to the residual way of life.

SIZE. Both sockeye and coho residuals grow more slowly than their anadromous siblings, but the difference is greater in the case of the sockeye. For sockeye it was also possible to demonstrate difference in previous rate of growth of the migrating and non-migrating fractions of the population—both at the time of yearling migration and at the time of two-year-old migration (Ricker, 1938). No data are available for a comparison of yearling migrant and non-migrant coho, but in the one year of record the two-year-old migrants did not differ in size from those taken in the lake at the same time (Figure 3).

COLOUR. In both species residuals are on the whole duller coloured at maturity than are anadromous examples. But whereas some coho residuals can be mistaken for anadromous fish, no residual sockeye could cause similar confusion—at Cultus Lake at least.

REPRODUCTION. Sockeye and coho are alike in that the reproductive potential of the residual population is very low. Among coho this results chiefly from an unexplained scarcity of adults of both sexes at spawning season—presumably the result of "natural" mortality toward the end of their third year of life. That sockeye residuals are limited in respect to reproductive potential is apparent from the scarcity of females among them. Such females as there are seem to mature eggs normally, regardless of their small size as compared with anadromous females. However, no tests of the fertility of the sexual products of mature residuals of either species have been made.

PERMANENT FRESHWATER POPULATIONS. In addition to the residual type of freshwater sockeye, there are also sockeye which live permanently in freshwater, often in lakes which cannot be reached from the sea. These are called *kokanee*. By contrast, coho are not known to have permanent freshwater populations in North America, either naturally or as a result of transfer of eggs to new habitats. Many such transfers have been made, and it has even been possible to take fertile spawn artificially from coho maturing in fresh water (Anon., 1951). However, the experience of fish-culturists to date has been that although coho taken to isolated lakes will usually grow well and provide fishing, they do not maintain themselves (Needham, 1938). The only claim that a transplanted stock has reproduced itself naturally, when migration to and from the sea is barred, is apparently that of Hasler and Farner (1942), who reported that in Crater Lake, Oregon, there were coho of two-year classes that had not been stocked artificially. However Wallis and Bond (1950) report no coho surviving there in recent years, and even imply that the fish of the classes reported by Hasler might have been kokanees.

The word "land-locked" is used rather loosely in this connection. Schultz (1934) described a small run of "land-locked" cohoes in a tributary of Lake Washington near Seattle—a lake that is open to the sea. However there is no information concerning the parentage of these fish. It is possible and even likely that they too are residual progeny of anadromous coho spawners, which latter are common in the same lake (Royal and Seymour, 1940).

COMPARISON OF LAKE AND STREAM COHO

There are two principal differences between the Cultus Lake coho and coho of stream populations. One is the relative abundance of residual fish. Studies of stream coho populations in British Columbia have not shown any residual spawners in that habitat. It is true that facilities for obtaining or recognizing residuals in streams have been meager, but their presence in numbers approaching those of the lake would certainly have been detected.

The other striking difference between the coho of the two habitats lies in the production of smolts. The smolts produced in Cultus Lake have varied from 2.5 to 3.7 per female spawner in normal years, with up to 15.4 per spawner under conditions of predator control (Table VII). Four years' data from Nile Creek on Vancouver Island show a range of 18 to 44 smolts per female (Wickett, 1951). In another creek the range was 15 to 16 smolts per female (unpublished data of J. G. Hunter). Obviously, natural smolt production at the lake is much inferior to that in the creeks.

For survival from smolt to adult stage data are more meager, but the one observation of return of marked fish at Cultus Lake (a minimum value of 8.1 per cent) is above the average of creek observations.

INTERRELATIONS OF LAKE AND STREAM COHO AT CULTUS LAKE

A fairly large and presumably self-sustaining anadromous coho population occurs in Sweltzer Creek. A considerable part, possibly one-quarter, of the total

run entering the creek goes on into the lake each year and spawns above it, but the fry and smolt migrants that such fish produce are few. They are not nearly numerous enough to maintain the lake's adult run from year to year, even at the rather high smolt-to-adult survival rate observed for the year-class of 1925, and the lake population is perpetuated by large contributions of adults from the creek population in some or all years.

The poor production of smolts by the lake is at least partly the result of the fact that most young coho do not leave the lake. They grow in the lake and remain abundant through the spring and early summer of their third year of life, but soon afterward they become scarce and very few seem actually to survive to maturity. The record of two years when few or no anadromous coho entered the lake shows that residual coho do not reproduce themselves to any significant degree; indeed there is as yet no evidence that they reproduce at all.

If the residual coho contribute little or nothing to the maintenance of their own numbers, or those of the anadromous stock, then their continued abundance is a fact calling for explanation. How can a situation be maintained in which half or more of the members of a population consistently adopt behaviour which prevents them contributing to the reproduction of the group? Should we not expect the genes conducive to such behaviour to be eliminated from the population rather rapidly? Present data have not provided any unequivocal explanation of this phenomenon, but an hypothesis may be put forward that can serve as a basis for experimentation. Our suggestions are: (1) that anadromous salmon which live in or above lakes need a somewhat more specialized series of congenital behaviour adaptations to get them out of the lake and on the way to sea, than do those which can proceed directly down a river to salt water; (2) that the hereditary factors determining this behaviour are not present, or are imperfectly present, in races of coho which spawn below the lowermost lake of their watershed or in streams which lack lakes; and (3) that since the Cultus Lake spawners come to a large extent from Sweltzer Creek fish, they largely lack the necessary adaptation and consequently their progeny mostly remain in the lake.

Hoar (1951) has described the behaviour of stream coho smolts at time of migration. He suggests that "three changes in behaviour, associated with the smolt transformation of coho, result in activities which lead to a seaward movement. . . . These are the loss of strong territory selection, the development of aggregating tendencies and a lowered threshold for stimulation during the night. In addition . . . the migrants prefer deep water." Primarily as a result of the increased nocturnal activity, "the transformed coho are gradually displaced toward the sea" by the river current. Behaviour similar to the above has been indicated also for Atlantic salmon (Huntsman, 1945, 1948), and it seems adequate to get smolts to sea *from rivers*. For smolts in lakes, however, this behaviour would not suffice. Undirected nocturnal movement would take smolts toward the lake's outlet no more frequently than to any other part of the shore, and a preference for deep water would make them actually avoid any point shallow enough to bring them under the influence of the outflowing current. What is required is behaviour which will ensure that almost all smolts arrive at the lake's

outlet within the rather limited time over which migration takes place. Just what kinds of reaction have this effect remains unknown. No observations of smolt behaviour in lakes are available for coho. Sockeye smolts have been observed in lakes during the time of migration. At Cultus Lake many of them move inshore to water about three feet deep, where large schools can be seen moving parallel to shore, either up or down the lake, both by night and by day. Whatever direction such a school adopts, it must eventually reach the outlet if it maintains a constant direction relative to the shore. However, other schools may be seen near the surface in open water, moving in the direction of the outlet, and this is apparently the usual procedure in certain other lakes. What environmental stimuli direct such movement is unknown as yet. On first entering the current of the outlet stream, the sockeye orient themselves upstream but do not swim vigorously enough to prevent their being carried slowly downstream—although they do make occasional dashes forward (Foerster, 1929).

If coho smolts are to leave a lake or traverse a lake on their seaward migration, it seems essential that they, no less than sockeye, should exhibit some type of directed behaviour at that time. And there are, of course, many runs of coho which spawn above lakes much larger than Cultus; for example the Birkenhead River coho must traverse both Lillooet and Harrison Lakes on their way to salt water. On the other hand, cohoes which spawn in most coastal streams have no need of such behaviour, and the capacity for it may well be poorly developed or lacking in the fish of such runs. At Cultus Lake the situation is intermediate. The Sweltzer Creek run is a stream-type unit similar to many other stream populations in the area. It does not require a behaviour pattern which would get its smolts out of a lake, and it may even receive a fairly free admixture of individuals from other runs of the region which are not at all close to any lake. On the other hand, some coho smolts do leave the lake and return to it, so a modicum of capacity for lake-leaving behaviour is evidently present in the heredity of the Cultus fish. If the lake population could be isolated from that of the creek, it seems likely that a population could be selected, in relatively few generations, which would have the necessary behaviour to produce nearly all migrants and very few residuals. However, it would suffer an initial decrease in numbers and would run the risk of being exterminated during the period of intensive selection.

Some aspects of the hypothesis above could be tested by experiments on coho smolts to determine their behaviour in bodies of water simulating a lake in size and form. It would be particularly informative to determine whether or not there are differences in behaviour patterns between smolts of short coastal streams and those which live in or migrate through lakes.

ACKNOWLEDGMENTS

We are greatly indebted to Mr. Loyd A. Royal for making available information obtained by the International Pacific Salmon Fisheries Commission at Cultus Lake since 1938, and for reading the manuscript. Dr. Ferris Neave has called our attention to the available information on the life history of stream

coho with which the lake fish have been compared. He and other members of the staff of the Pacific Biological Station have made useful comments upon the material presented, as have Drs. W. A. Clemens and W. S. Hoar of the University of British Columbia.

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Colour Pattern of Humpback Whales from the Coast of British Columbia

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ABSTRACT

The colour of 184 humpback whales (*Megaptera nodosa*), was studied at the Coal Harbour whaling station on Vancouver Island during the summers of 1949, 1950 and 1951. The colour of the throat region, the flippers and the flukes were classified separately, according to the amount of white present in each of these three regions. Humpback whales from the coast of British Columbia differ from those taken at South Georgia, South Africa, New Zealand and Madagascar in being darker in colour. Males are lighter in colour than females, on the average. No definite change in colour occurs with increase in length.

GENERAL

A SYSTEMATIC EXAMINATION of the colour of 184 humpback whales (*Megaptera nodosa*), was carried out at the Coal Harbour whaling station on Vancouver Island during the summers of 1949, 1950 and 1951, in order to compare the colour pattern of humpbacks from British Columbia with those from other localities. To date there has been no comprehensive study of the colour of humpbacks from any locality in the northern hemisphere. Isolated observations of the colour of individuals or small groups of individuals have been recorded, but, because of the wide range of individual variation in this feature, these are of little value in describing the average coloration of a population of humpbacks.

A general description which applies well to the colour of humpbacks whenever they occur is given by True (1904) in summarizing reliable observations on European humpbacks. These observations show:

1. That the colour is normally black on the head, back and sides and around the caudal peduncle;
2. That the colour of the throat and chest, and the median line below, at least as far back as the anus, is varied to a greater or less extent with white spots, streaks, and larger areas;
3. That the flippers have the lower surface almost white, but the upper surface varied white and black, in some cases almost entirely black, in other cases the distal three-fourths or nearly the whole surface white;
4. That the flukes are largely black above, more or less white below.

True concluded that there is no important difference in colour between the American and European humpbacks. Descriptions of humpbacks from South Georgia and South Africa (Matthews, 1937), New Zealand (Lillie, 1915) and Madagascar (Angot, 1951) also agree with this general description.

OBSERVATIONS

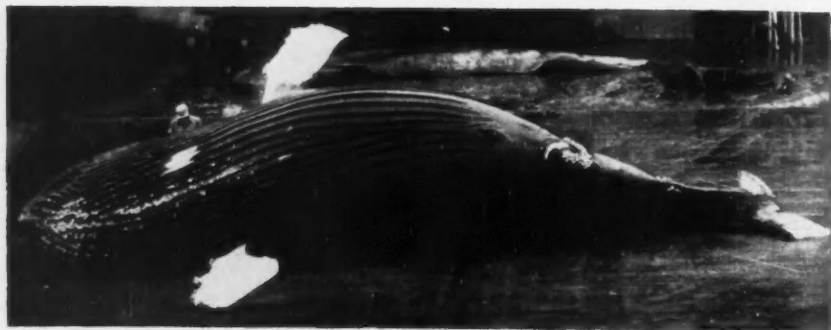
In this study the humpbacks are classified according to (1) the amount of white on the throat folds, (2) the location of the white on the flippers and (3) the amount of white beneath the flukes. Individual variation in the amount and location of white areas in these three regions is great. A large amount of white in the throat region is not necessarily accompanied by the presence of large white areas on the flukes or the flippers. It is, therefore, necessary to analyse the colour of each of these regions individually. Black areas are often marked with streaks, spots, rings or circles of white and white areas with similar markings of black, as illustrated by Lillie (1915). Usually these ornamentations occur at the borders between extensive regions of white or black. Superficial injuries caused by barnacles, abrasions by sharp rocks or lamprey attacks are superimposed as light marks on a dark background or as dark marks on a light background. Usually a short white splash occurs at the apex of the snout on the under surface. Frequently white areas occur at the umbilicus or in the genital region and occasionally a white line occurs along the ridge of the dorsal fin.

COLOUR OF THROAT FOLDS. The amount of white on the throat folds is classified in Table I and illustrated in Figure 1. The majority of humpbacks had very little white in this region. Occasionally, white marks were entirely absent. The tabulation shows that males are, on the average, whiter on the throat folds than are the females. Extensive white areas occurred in 20 per cent of the males and only 11 per cent of the females. A slight difference between the amount of white present on whales shorter than 40 feet and those 40 feet or longer is suggested by the tabulation. This slight difference may be merely the result of loss of pigment in places where barnacles have dropped off. The frequency of occurrence of extensive white areas in this region is approximately equal in both large and small whales.

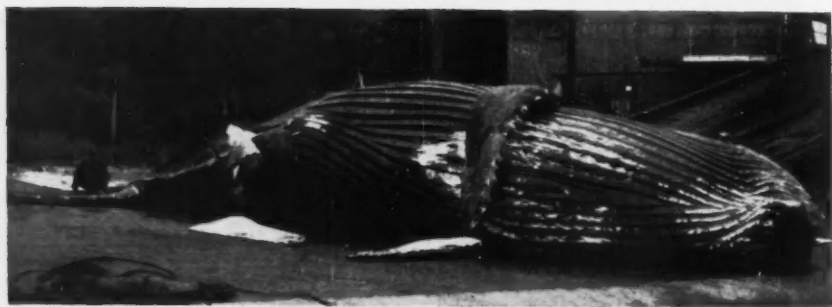
TABLE I. Colour of the throat region of British Columbia humpback whales.

Amount of white	Male			Female		
	Less than 40 feet	40 feet or more	Total	Less than 40 feet	40 feet or more	Total
Slight	34 (60%)	30 (52%)	64 (56%)	27 (77%)	24 (69%)	51 (73%)
Moderate	11 (20%)	16 (27%)	27 (24%)	4 (12%)	7 (20%)	11 (16%)
Extensive	11 (20%)	12 (21%)	23 (20%)	4 (11%)	4 (11%)	8 (11%)
	56	58	114	35	35	70

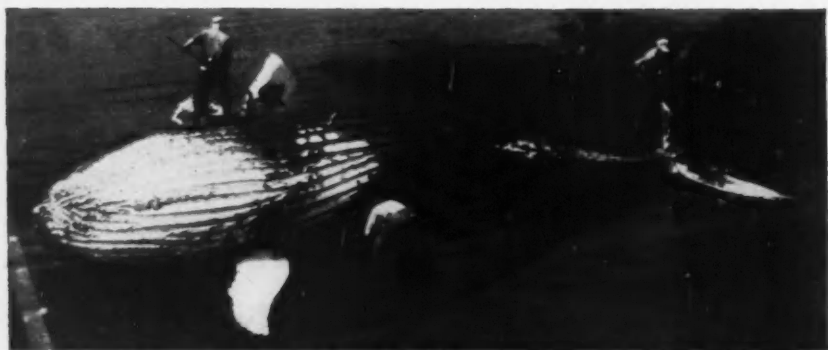
COLOUR OF FLIPPERS. The usual colour of the flippers is white on the inside and black on the outside, usually with a narrow fringe of white along the lower border. When white appears on the outer surface of the flipper, it is usually on the distal part, along the lower border. Frequently a black area extends from the insertion distally along the upper outside border. The inner surfaces are usually white. Sometimes, however, they are black, except for the presence of streaks, spots, or circles of white. Frequently a band of black extends from the insertion distally along the upper inside border. In almost three-quarters of the whales of



(a)



(b)



(c)

FIGURE 1. Coloration of humpbacks from the coast of British Columbia according to the amount of white on the ventral folds.

- (a) Slight
- (b) Moderate
- (c) Extensive

both sexes the flippers were predominantly black on the outside and predominantly white on the inside. Table II shows a greater percentage of males with white predominating on the outside of the flippers. On the average these males had more white on the flippers than did the females.

TABLE II. Colour of the flippers of British Columbia humpback whales.

Colour of flippers	Male	Female
Predominantly black on outside and white on inside	82 (72%)	51 (73%)
Predominantly white on outside	20 (17%)	8 (11%)
Predominantly black on inside	12 (11%)	11 (16%)
	114	70

COLOUR OF FLUKES. The entire flukes could be examined in only a small number of whales, because their tips are usually cut off at sea. Invariably the flukes are dark above, except for small white specks, circles or streaks. There is great variation, however, in the amount of white on the under surface. Table III shows that almost half the males have extensive white areas extending almost to the mid-line of the flukes, but only in one out of 15 females was this the case. The white area extended to the mid-line in only one male. Generally the males have white beneath the flukes more often and to a greater extent than do the females.

TABLE III. Colour of the flukes of British Columbia humpback whales.

Amount of white beneath flukes	Male	Female
Slight (predominantly black)	11 (33%)	11 (73%)
Moderate (mottled white)	8 (24%)	3 (20%)
Extensive (extending almost to mid-line)	14 (43%)	1 (7%)
	33	15

COLOUR OF FLANKS AND BELLY. Lillie (1915) classified the colour pattern of New Zealand humpbacks into four main and three intermediate types or stages in the progressive covering of the ventral surface, by the encroachment of the dorsal black coloration over the flanks and belly. The black colour is shown to creep down the sides in three bands which coalesce in the extreme type (group 4), one behind the flippers and over the posterior portion of the ventral grooves, one below the dorsal fin and one a short distance proximal of the flukes. According to this classification all but one humpback taken off the British Columbia Coast was in colour group 4. The one exception, a large female, corresponds to Lillie's intermediate group 3-4. It had an extensive area of white on the throat folds and breast, white patches on either side of the umbilicus, white around the genital and mammary slits and along the mid-ventral ridge, and white beneath the flukes and flippers. Many white specks covered the ventral surfaces, but they did not reach up to the insertion of the flippers as in Lillie's group 3. Only in this one individual were extensive areas of white present between the termination of the ventral grooves and the flukes.

COMPARISON WITH OTHER POPULATIONS. The foregoing observations do not lend themselves readily to comparisons with available descriptions of other hump-

back populations, except in general terms. The difficulty lies in the interpretation of arbitrary classifications to which the British Columbia humpbacks do not conform closely. Using Lillie's classification Matthews (1937) concluded that South Georgia and South Africa humpbacks, 60 per cent of which are in colour group 4, appear to be darker than New Zealand humpbacks. Lillie's group 4 is interpreted as including all but one of the humpbacks studied in British Columbia. Hence, the British Columbia humpbacks are, on the average, darker than those from South Georgia, South Africa and New Zealand. A classification describing the colour of humpbacks taken off the coast of Madagascar (Angot, 1951) uses two principal types which appear to be similar to Lillie's groups 3 and 4. These two types were found to occur in approximately equal numbers. The humpbacks from Madagascar are, therefore, lighter in colour on the average than those from British Columbia.

The colour of the Discovery whales, the New Zealand whales and the British Columbia whales is similar in that the females tend to be darker than the males. In each of the three morphological regions examined in the whales from British Columbia, white areas were found to be more extensive on the males and extensive white areas were found in a larger proportion of the males.

Angot (1951), in describing the colour of Madagascar humpbacks, found that the dark extreme type predominated in larger whales. From this he concluded that as the whales grow older the colour becomes darker. This conclusion is in direct contradiction to the theory supported by True (1904), that young whales are dark in colour and become whiter with age. The humpbacks studied by the Discovery Committee (Matthews, 1937) do not show a definite change in colour with size or age nor do the whales from the coast of British Columbia.

A shortcoming of the value of classifications such as those used by Lillie, Matthews and Angot, which are designed to describe the colour of humpbacks for comparative purposes, is the practice of grouping the colour of flippers, flukes, throat and post-umbilical regions into composite types. There is no constant relationship in the colour of these regions. Consequently, it is necessary to classify each region separately.

DISCUSSION AND CONCLUSION

In view of the great variability in the colour of humpbacks, not much systematic importance can be attached to this feature. It is apparent, however, that although all colour types may appear in any one locality, certain colour types predominate in each locality. Recent marking recoveries have shown that southern hemisphere humpbacks are segregated into several communities between which little interchange occurs (Mackintosh, 1947). The differences in predominating colour types between at least two of these communities, the New Zealand group and the South Georgia group, would seem to be a manifestation of geographical isolation.

The occurrence of separate communities of humpbacks in the northern hemisphere has not yet been clearly demonstrated, but it is probable that separate communities do occur in northern waters and that these may be characterized

by predominating colour types. If the existence of these communities is to be demonstrated by reference to colour differences it is essential that a good colour classification be established and uniformly adhered to as a basis for comparison. It is essential that the colour of the throat region, the flippers, the flukes and the post-umbilical region be classified separately because the colour of these regions do not bear a constant relationship to one another. Furthermore, it is essential that large numbers of observations be made in order to demonstrate the range of variability of colour in each population. Statements such as that made by Olsen (Matthews, 1937) to the effect that humpbacks with flippers coloured white on the outside are the rule in the northern hemisphere, must be regarded as unwarranted until more information is available.

In spite of the individual variation of the colour of humpbacks, populations from different localities may be characterized by certain colour types depending upon the amount of white present and the location of white areas. The humpbacks from the coast of British Columbia differ from those taken at South Georgia and South Africa, New Zealand and Madagascar in being, on the average, darker in colour. The males are on the average somewhat lighter in colour than the females in the throat region, on the flippers and on the flukes. No changes in colour with increase in length were detected.

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On the Age, Growth, Migration, Reproductive Potential and Feeding Habits of the Arctic Char (*Salvelinus alpinus*) of Frobisher Bay, Baffin Island

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"CALANUS" SERIES, NO. 3

ABSTRACT

The Arctic char (*Salvelinus alpinus* Linn.) was studied, in the summers of 1948, 1950 and 1951, about the mouth of the Sylvia Grinnell River, Frobisher Bay, Baffin Island.

Otoliths are shown to be reliable age indicators and are used for age determination. Because of deficiencies in the sampling of the fish a calculated growth curve has been constructed. The calculated growth rate is obtained by showing the relationship between otolith width and fish length and expressing it in the equation: $\log(\text{fish length}) = -1.503 + 1.982 \log(\text{otolith width})$. The relationship between otolith ring diameter and fish age is demonstrated, and from these two relationships the lengths of fish at earlier ages are calculated.

The char grow very slowly, and reach an age of more than 24 winters. They migrate to the sea in late June and return to fresh water from late July until September. The first movements to the sea probably occur during the fifth, sixth and seventh summers. Sexual maturity in the females is reached at a length of about 45 cm., and at an age of approximately 12 winters. Egg counts of maturing fish averaged 3,589. Only about 33 per cent of the females over 45 cm. were maturing. At least 30 food species were found in the stomachs.

Additional growth, fecundity and food studies were made on small samples from George River, Herschel Island and Adlorilik.

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INTRODUCTION

THE GROWTH RATE of the Arctic char (*Salvelinus alpinus* Linn.) of Canadian waters has not previously been studied, nor has it been the subject of more than slight attention in any of the parts of its wide range. Data on the aging and rate of growth of the Arctic char are presented with the object of showing the general pattern of growth of this fish in Frobisher Bay, Baffin Island.

The material consists of 1,566 specimens of Arctic char from the Sylvia Grinnell River, Frobisher Bay, taken as follows:

Year	No. of fish	Type of fishing gear
1948	386	gill nets of 6½", 6" and 4" mesh (stretched)
1950	320	gill nets of 6", 5", 4" and 1" mesh (stretched); minnow traps; hand nets
1951	860	gill nets of 5½", 4" and 2½" mesh (stretched); minnow traps; hand nets; gaffs; jigs

In addition, small samples from George River, southeastern Ungava Bay, Herschel Island, N.W.T. and Bay of Two Rivers, Frobisher Bay, were taken with gill nets.

The Arctic char is an anadromous and landlocked salmonid found in cold waters of the northern hemisphere. It has been recorded from Greenland, Iceland, Svalbard (Spitsbergen), Novaya Zemlya, Bear Island, northern Norway, northern Siberia, Alaska and northern Canada, in which regions the anadromous form is found. In addition, the land-locked form is found in the far north, and also in areas to the south of the sea-run char, in lakes of Sweden, southern Norway, Finland, England, Ireland, Scotland, the Orkneys, the Shetlands, the Alps and the U.S.S.R. (Jensen, 1948).

A variety of names has been given to the Arctic char in different parts of its range, and in many cases the characters upon which different specific and subspecific names have been based are obscure. Dymond and Vladikov (1933) have included in the *Salvelinus alpinus* group the forms found in northern North America and Asia to which the following subspecific names have been given: *alpinus*, *malma*, *leucomaenis*, *erythrinus*, *kundscha*, *spectabilis*, *pluvius*, *imbricus*, *arcturus*, *naresii*, *alipes*, *stagnalis*, *aureolus*, *oguassa*, *marstoni* and *fontinalis* (the latter an Asiatic subspecies of *alpinus*, not to be confused with the American brook trout).

Because of the confused state of the taxonomy of these fish, the populations dealt with in this paper are considered as *Salvelinus alpinus*, with the possibility of subspecific classification, following the suggestion of Dymond (in Manning, 1942) who said, "There are undoubtedly local variations among Arctic Char as among other wide-ranging species, but they have not yet received sufficient study to enable us to know which of them are worthy of sub-specific names."

THE SYLVIA GRINNELL RIVER

Field work was carried out on the Arctic char in Frobisher Bay, southeastern Baffin Island, during the summers of 1948, 1950 and 1951. The work of 1950 was done by John Wright, while that of the other years was carried out by the author.

Fishing in 1948 and 1950 was conducted in association with a commercial fishing operation, with Wright and the author acting as scientific observers, based for the most part on board ship in Koojesse Inlet, while that of 1951 was done independently from a shore base by the author alone.

The Sylvia Grinnell is a southward-flowing river originating in the interior of Baffin Island and emptying near the northwestern extremity of Frobisher Bay, at about $63^{\circ} 44'$ north latitude, $68^{\circ} 34'$ west longitude. A lake, not seen by the author, but reported by residents of the area, apparently exists some 25 to 30 miles inland from the mouth of the river, and it is in this region that the char are said to spend the winter.

The lower portion of the Sylvia Grinnell and the bay adjacent to its mouth are shown in Figure 1. The river empties into an arm of the bay over four separate waterfalls, the height of which vary with tidal conditions from almost nothing to some 12 feet. This height does not equal the tidal variation of the upper part of Frobisher Bay, because of the nature of the estuary into which the river flows. At low tide the water level about the base of the falls remains higher than that of Frobisher Bay, water being added from the river and lost over shallow rapids which appear at several places between the falls and the bay. Thus from the time of the appearance of these rapids during the falling tide until the next rising tide has obliterated them, the water level about the falls remains fairly constant, and it affected by only the latter part of each rise in tide. At no time during the summer of 1951 did the salt water extend above the falls. North of the falls, in the lower five miles of the river, there are several sections of rapids and the water flow is fast throughout.

The river itself and the bay into which it flows are frozen over during a large part of the year. In 1951 the ice covering over the river had only recently broken on June 10, and the area below the falls and extending out over the bay to the limit of visibility was iced over completely. By June 25 the area about the mouth of the river had become relatively clear, apart from fast-ice remaining along the shore, and the flow of ice down the river had diminished sufficiently to permit the use of nets. The fishing region remained ice-free throughout the rest of the 1951 season. Ice was absent during all the 1948 fishing period, and except for a brief wind-driven return between August 19 and 23, the 1950 fishing was ice-free.

The tidal rise and fall are extensive in Frobisher Bay. The mean spring tides are about 32 feet above the normal low-tide mark (Canada, Dept. Mines and Tech. Surv., 1951) and serve to alter greatly the conditions about the mouth of the Sylvia Grinnell River. While at high spring tides the falls are almost obliterated, and nearby islands are reduced (Figure 1), at low spring tides the falls are thundering masses of water and the coastline below them is altered by the appearance of large expanses of dry land. Navigation up to the falls from the bay, even in the smallest craft, becomes impossible at low tide.

FISHING METHODS

Most of the fishing was done in the estuary adjacent to the mouth of the Sylvia Grinnell River. Additional fish were taken from nets set off islands in

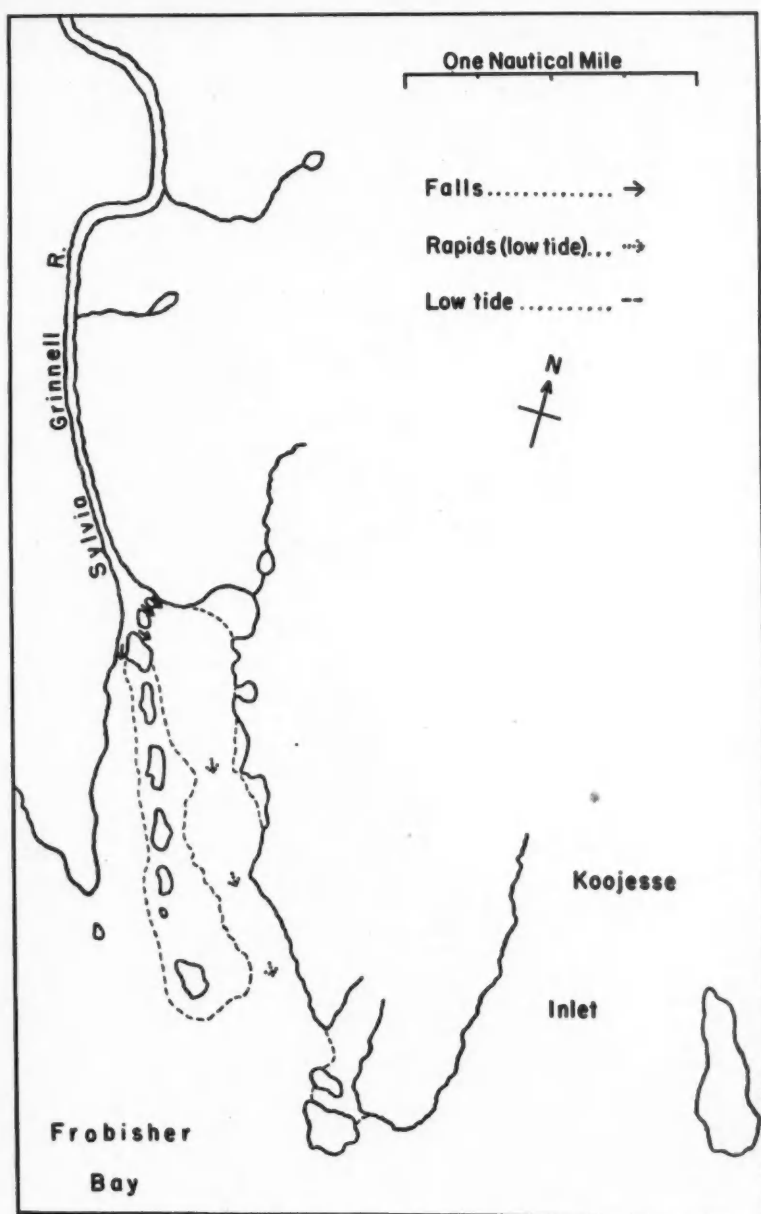


FIGURE 1. Map showing the mouth of the Sylvia Grinnell River, Frobisher Bay, Baffin Island.

nearby parts of the bay and in the river above the falls, also from small pools and streams leading into the river.

Examination of the char was carried out as soon as possible after their capture. In 1948 and 1950, when most of the specimens were acquired from commercial fishing nets and only a part of the catch could be studied, care was taken to secure a random sample for examination. Following each visit to the nets the fish were taken to the cutting tables. They were placed in large containers under the tables, and were selected for examination by the observer thrusting one finger into the fish container, which he could not see, and taking the fish which had been touched first. In 1951 all the fish collected were examined. Length measurements were made to the nearest half centimetre, and are expressed throughout as fork length, that is length from the anterior extremity of the fish to the foremost point on the posterior indentation of the caudal fin.

Fishing was done principally with gill nets, also with minnow traps, hand nets, gaffs and jigs. Gill nets used during the three seasons of fishing were of 1-, 2½-, 4-, 5-, 5½-, 6- and 6½-inch stretched meshes, of both linen and cotton. Minnow traps were of the common mouth-to-mouth type of fine wire mesh, with apertures at either end of about one-inch diameter. Gaffs used were fashioned by attaching jigs or large hooks to wooden poles and cod jigs were used with a length of line.

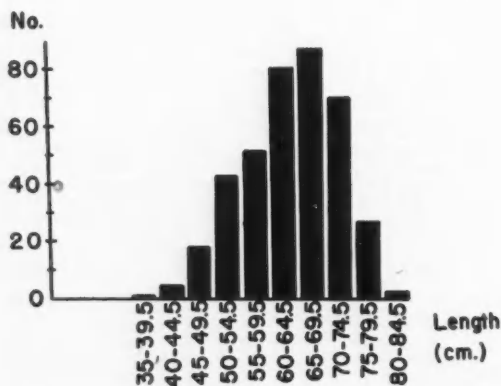


FIGURE 2. Frequency histogram of the 1948 sample.

Identical fishing equipment was not used during each of the three seasons, and it is probable that the smaller individuals were not sampled adequately, as will appear below. Because of this variety in the sampling methods used, and the probability of inaccurate sampling of the smaller specimens, a consideration of the sampling methods of each of the three seasons is necessary, in order to correct possible misinterpretations of the observed mean age-length relationship of some of the younger age groups.

Histograms showing the size frequency of samples from each of the three

fishing seasons appear in Figures 2, 3 and 4, and one of the combined frequencies for the three years is shown in Figure 5. In these diagrams the bars above the base line indicate fishing results almost entirely from the use of gill nets (a small number of large specimens were taken by gaffs and jigs), while those below the base line represent fish taken by minnow traps, hand nets, jigs and gaffs (except for the few large specimens above). These raw data are given in Table I.

In 1948 gill nets of 4-, 6- and 6½-inch meshes only were used. By far the greatest use was made of the 6-inch mesh nets, and comparatively little of the other sizes, the resulting mode in the 65- to 70-cm. size group reflecting this use of nets of a size selected for commercial fishing.

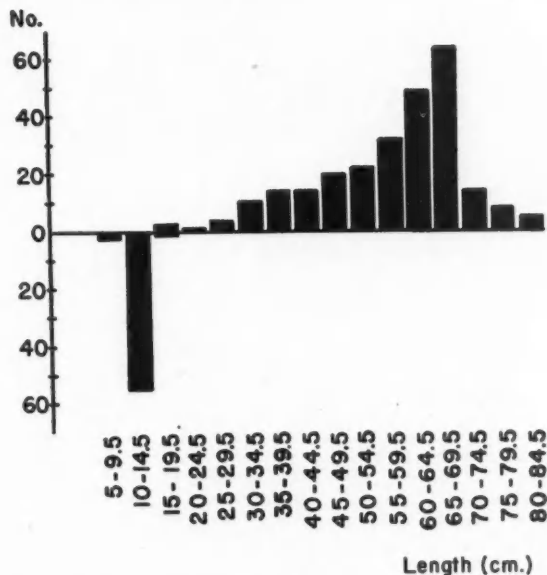


FIGURE 3. Frequency histogram of the 1950 sample. Fish taken in gill nets are represented above, those taken by other methods below the base line.

In 1950 a greater variety of techniques was utilized, including gill nets of 1-, 4-, 5- and 6-inch meshes, and in addition, minnow traps and hand nets. As in 1948, 6-inch meshes were used much more extensively than were other gill nets, and again the length group 65 to 70 cm. appears as the largest. A more rapid falling off of numbers of those fish exceeding in length 70 cm. in 1950, compared with 1948, may be accounted for by the absence of nets of 6½-inch mesh in 1950, although the maximum length was not reduced by using no 6½-inch mesh in 1950. As in 1948 much less use was made of nets smaller than 6-inch, but 1- and 4-inch meshes accounted for the capture of some smaller fish than had been taken in 1948. Shown by the inverted bars in Figure 3 are those fish captured by methods other than gill nets, that is by minnow traps and hand nets, largely the

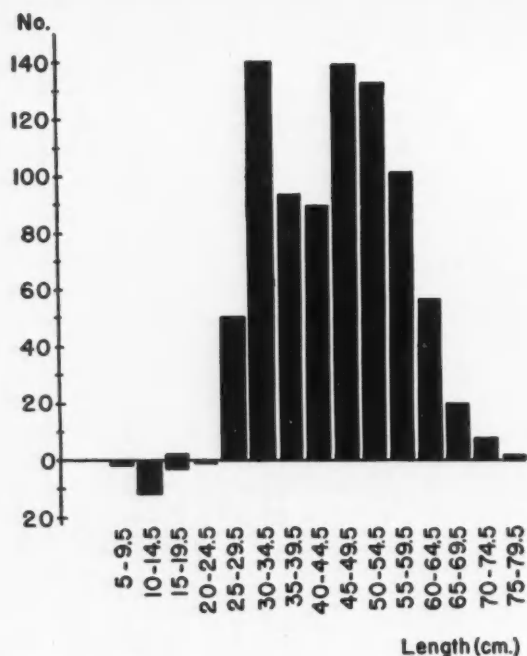


FIGURE 4. Frequency histogram of the 1951 sample. Explanation as in Figure 3.

TABLE I. Length frequency, Sylvia Grinnell River, 1948, 1950 and 1951.

Length group cm.	1948				1950				1951				Total			
	♂	♀	?	T	♂	♀	?	T	♂	♀	?	T	♂	♀	?	T
0-4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-9.5	0	0	0	0	0	1	2	3	1	1	0	2	1	2	2	5
10-14.5	0	0	0	0	21	24	10	55	6	6	0	12	27	30	10	67
15-19.5	0	0	0	0	0	3	1	4	1	4	0	5	1	7	1	9
20-24.5	0	0	0	0	0	0	1	1	0	2	0	2	0	2	1	3
25-29.5	0	0	0	0	2	1	1	4	21	30	0	51	23	31	1	55
30-34.5	0	0	0	0	4	3	4	11	75	66	0	141	79	69	4	152
35-39.5	0	1	0	1	5	4	5	14	44	50	0	94	49	55	5	109
40-44.5	3	2	0	5	4	7	3	14	43	47	0	90	50	56	3	109
45-49.5	7	11	0	18	3	12	5	20	70	69	1	140	80	92	6	178
50-54.5	10	30	3	43	5	11	6	22	73	60	1	134	88	101	10	199
55-59.5	29	21	2	52	16	11	5	32	63	39	0	102	108	71	7	186
60-64.5	32	46	2	80	29	11	9	49	34	23	0	57	95	80	11	186
65-69.5	29	57	1	87	43	9	12	64	12	8	0	20	84	74	13	171
70-74.5	36	33	1	70	8	5	1	14	7	1	0	8	51	39	2	92
75-79.5	24	2	1	27	6	1	1	8	2	0	0	2	32	3	2	37
80-84.5	3	0	0	3	4	0	1	5	0	0	0	0	7	0	1	8
	173	203	10	386	150	103	67	320	452	406	2	860	775	712	79	1,566
	♂, 46.0%				♂, 59.3%				♂, 52.7%				♂, 52.1%			
	♀, 54.0%				♀, 40.7%				♀, 47.3%				♀, 47.9%			

former. The traps were used effectively only in fresh water and captured fish from the minimum size taken (8.5 cm.) to 15 cm. only, the only larger specimen (16.5 cm.) having been taken by hand. While during the 1950 season, which lasted from about the middle of July until near the end of August, most of the fishing was done as a commercial venture, additional gear was taken to the field in order to sample the smaller individuals in the population, smaller fish than had been taken in 1948.

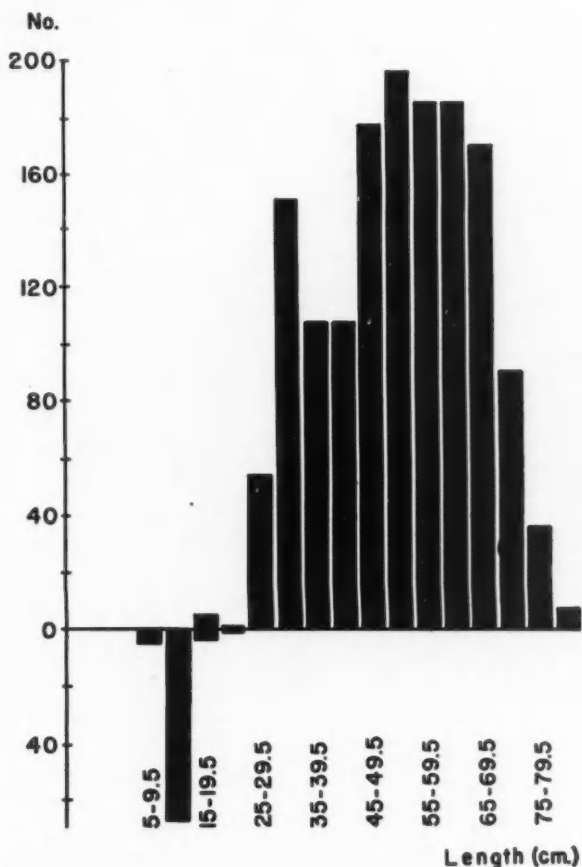


FIGURE 5. Frequency histogram of the 1948, 1950 and 1951 samples combined. Explanation as in Figure 3.

In 1951 gill nets of 2½-, 4- and 5½-inch mesh sizes were used. In Figure 4 the frequency of the gill-net-caught fish shows extensive use of the three net sizes. The presence in the sample of fewer fish in the 35- to 44.5-cm. group than in size

groups both smaller and larger may be attributed to the size difference between the $2\frac{1}{2}$ - and 4-inch meshes, which resulted in less efficient fishing for the members of this size group than for those slightly smaller and larger.

The $2\frac{1}{2}$ -inch meshes, although used extensively, captured only one fish in the 15- to 19.5-cm. group (18.5 cm.) and no others less than 26.5 cm. (The 1-inch mesh used in 1950, used much less frequently, took only three fish, to a minimum of 16.5 cm.) In the inverted section of Figure 4 the single specimen of the 20- to 24.5-cm. group and two of the three between 15 and 19.5 cm. (17 cm. each) were taken by jigging, while all smaller fish were obtained either in minnow traps or by hand. As in 1950 no fish longer than 15 cm. was taken by a minnow trap.

Figure 5 shows combined frequencies for the three years. It is evident that a disproportionately small number of fish was sampled from the lower part of the size range, particularly those between 15 and 26.5 cm. in length. The gap in the size range from 20.5 to 26.5 cm., and the small sample taken between 15 and 20 cm. may be due to one of two things: inadequate sampling of fish of this size, or a real gap in the population. The most probable explanation for any real gap in the population would be rapid growth of the fish of this size, compared with the rate of growth of those immediately smaller and larger. This does not appear to be so, as is pointed out below in the discussion on the growth rate.

Between the specimens taken by a 1-inch net and all but one of those obtained from $2\frac{1}{2}$ -inch nets there is a gap in length, from 20.5 to 26.5 cm., from which no fish were taken. This may be explained on the limitations of these two net sizes which permitted this size group to remain immune from capture, the largest fish taken by a 1-inch mesh net being considerably smaller than the smallest fish which normally would fall prey to a $2\frac{1}{2}$ -inch mesh net. Although no fish were taken in minnow traps in salt or brackish water (below the falls), three specimens of less than 15 cm. were caught in the area by hand. Fish were present, therefore, in the area where gill nets were used, which were smaller than the net sampling would indicate, but were sampled inadequately, available fishing gear not being suitable for their capture. Similarly, larger fish were taken by hand in fresh water, during the sea-run period, than could be sampled by the minnow traps, although none of this size was taken by the $2\frac{1}{2}$ -inch mesh nets. Thus fish of a size group which the fishing gear was not suitable for sampling were present in fresh water, during the period following migration to the sea.

It is evident that by the use of more varied gear many more fish than those obtained could have been taken in salt water, down to at least 15 cm. Similarly among those sampled in fresh water, it is probable that the use of traps suitable for the taking of larger fish would have provided a larger sample greater than 15 cm. in length from fresh water. The 5- to 9.5-cm. length group appears not to be numerous in the lower portion of the freshwater system, as suggested by the capture of very few specimens in the minnow traps, the taking of none smaller by hand, and the observation of none in the field. The 8.5-cm. minimum size taken by the minnow traps in fresh water seems to be somewhat in excess of the minimum effective size of the traps, in that the traps might be expected to capture

smaller char than those taken in them, their mesh being small enough to confine fish of less than 8.5 cm. (Sticklebacks of less than 5 cm. were taken in the traps.) Thus it is probable that fish approaching the smallest present in this part of the freshwater system were obtained.

From this there is good reason to suspect that the sampling of fish in the 15- to 26.5-cm. size range lacked the intensity of that applied to smaller and larger sizes, therefore that a gap in the population need not exist to explain the frequency distribution. It is evident that the estimation of the mean lengths of age groups from the sample, the length ranges of which are interrupted by this length gap, cannot be accomplished by a mere averaging of the sampled lengths within a year group. This requires the estimation of calculated mean lengths for specimens of these age groups, and is discussed below.

THE OTOLITHS OF THE CHAR

The otoliths were taken from the fish as soon as possible after capture. Most were kept dry, in envelopes, while a small number was preserved in an equal



FIGURE 6. The left otolith of a 9-winter specimen. A light area appears in the dark core because of cracks crossing the otolith.

mixture of glycerine and sea water. The largest otolith of the char is the sagitta, one being found in the sacculus of each inner ear. Because of their large size, compared to the other otoliths present, they were selected for age determination.

Whenever possible readings were made on both ear-stones of a pair, and good agreement was found usually between the two readings. When, however, only a single otolith was available or one showed itself to be distinctly clearer than the



FIGURE 7. Otolith from an 11-winter specimen.

other, only one reading was taken. In all cases where any real uncertainty existed concerning the count of rings, the readings were discarded, so that while otoliths from some 1,000 char were collected from the Sylvia Grinnell fish, ring counts were made on 807. Those kept dry proved greatly superior to those preserved in glycerine, in the clarity of the rings, especially the narrow marginal rings of the larger otoliths. It was possible to read most of them without cutting; others either were ground on their convex surface, or were cut transversely through the centre.

Determinations on the otoliths collected in 1948, and preserved wet, were

carried out by Miss R. I. Peterson of the Atlantic Biological Station, St. Andrews, N.B. The others were read by the author.

The otoliths collected range in size from about 1.5 mm. by 0.9 mm. to about 7.3 mm. by 3.5 mm. They are similar in general shape, the larger otoliths being relatively slightly longer than the smaller. As the otolith lies in the sacculus, a pointed projection, the rostrum, is directed dorsally and anteriorly. The medial



FIGURE 8. A 13-winter otolith.

surface is made up of two lobes, the larger of which is continuous with the rostrum, and separated from the smaller by a deep fissure. Laterally the otolith is fairly smooth and slightly convex. It is through this lateral surface that the readings are made most satisfactorily, either with or without grinding.

The otoliths were examined under a binocular microscope, using reflected light. They were viewed submerged either in water or in a water and glycerine mixture. The measurements were made with a micrometer eye-piece, and are expressed in units of the micrometer (one unit equals 0.064 mm.).

In the centre of the otolith is a dark core (under reflected light) around which

are arranged concentric alternating light and dark rings, these extending to the margin and becoming narrower towards the otolith edge. Some confusion arises in ring interpretation of many otoliths due to the presence of one or more cracks which cross the structure, passing in nearly all cases through the centre. Johnston (1938) has suggested that this is a common finding in otoliths. They may be due to the setting up of unequal stresses within the otolith during drying following



FIGURE 9. The right otolith of a 19-winter specimen.

removal from the fish. The light rings are considerably wider than the dark rings, and are interpreted as indicating periods of relatively rapid growth ("summer" growth). The dark rings are interpreted as representing periods of relatively slow growth ("winter" growth).

The year's cycle undergone by the char is in accordance with this interpretation. The winter months are spent in ice-bound fresh water, where feeding evidently is greatly reduced. During the summer, on the other hand, the environment is changed conspicuously. The fish leave the fresh water and migrate into coastal marine areas where the supply of food is abundant.

The otolith markings of the char appear to coincide with these two environmental phases, those taken during the early summer showing marginally a narrow, dark, "winter" growth band as the portion most recently deposited. With the progress of summer a light area appears on the margin, as evidence for more rapid "summer" growth. This light region, however, in the otoliths collected latest in the season (early September) had not reached a width com-

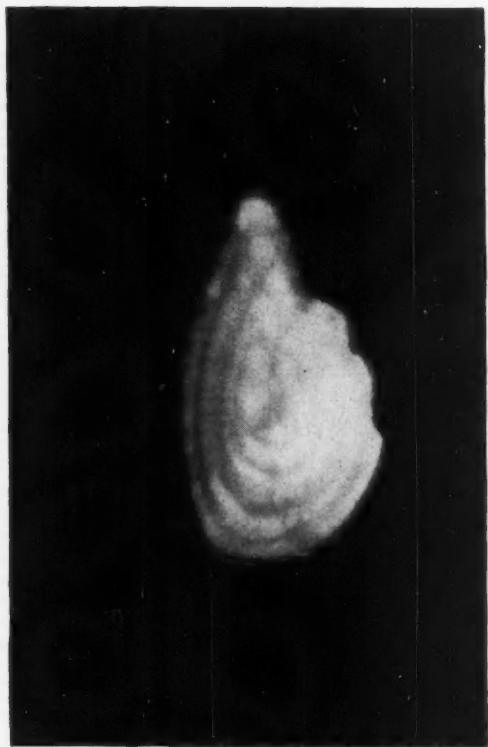


FIGURE 10. A 5-winter otolith. Evidence of the laying down of the fifth "summer" ring appears at the bottom and on the right side of the otolith.

parable to that of the previous "summer" band (allowing for the "summer" band being slightly narrower than the one preceding it in accordance with a reduced rate of growth with increasing age), so it appears that this deposition continues at least briefly during the early, autumn phase of freshwater life. There seems from this to be a slight delay in the laying down of the "summer" ring, in that its deposition is not fully in phase with the marine period of the char, but commences shortly after entrance into the sea, and continues apparently for a short time after entrance into fresh water. As the dark rings may be seen at their fullest

during the early summer, it follows that the laying down of these occurs between the fall and the succeeding summer, while the fish are in fresh water.

Because no sufficiently small specimens were taken, it cannot be stated with certainty when the dark core of the otolith is deposited, or when the otolith begins to form in the char. It is probable that eggs are deposited in the autumn, but the time of hatching is not known. It has been shown that the dark areas of the



FIGURE 11. A 13-winter otolith. A thirteenth "summer" ring is shown forming along the right side and at the tip of the rostrum. The centre of the core appears light because of cracks.

otoliths are deposited between the autumn and the succeeding summer, and that the dark core appears to be a winter deposit. From extrapolation of the curve showing the relation between otolith width and fish length (below) it is suggested that the otolith begins to form almost as soon as the fish begins to develop. From this the dark core is considered as representing the first winter of growth.

Photographs of six char otoliths are shown in Figures 6 to 11. In Figure 6, the left otolith from a 9-winter char illustrates the appearance of the ear-stones from a lateral view of the convex surface. Part of the dark core appears light in

the photograph because of cracks which radiate from the centre to the margin. In this otolith nine dark areas ("winter" growth), including the central core, are present, separating eight wider, light rings ("summer" growth). In Figure 7 an 11-winter otolith is shown, in which the rings appear clearly. Figure 8 shows a 13-winter otolith in which clear differentiation of the rings appears only on one side. Figure 9 is of a 19-winter right otolith. In Figure 10, a 5-winter otolith, the core is obscured by cracks. Along parts of the margin very slight evidence of a white area ("summer" growth) may be seen, at the bottom and on the right side, just above the centre. This fish was taken on July 15, 1951. In Figure 11, of a 13-winter specimen, further evidence of the laying down of the "summer" ring is shown, along the right side, and at the tip of the rostrum. This specimen was taken on August 11, 1951.

THE OBSERVED AGE-LENGTH RELATIONSHIP OF THE MATERIAL

Table II gives the results (expressed in winters of life) of otoliths read from 806 char of the Sylvia Grinnell River, also numbers of each year group, average length, and range in length of fish of both sexes in each year group.

Examination of the length range given for each age group shows interruptions in the ranges of the 7-, 8- and 9-winter fish, between those taken in 2½-inch-mesh nets and those obtained in the 1-inch-mesh net, in minnow traps and by hand.

TABLE II. Age, mean length and size range of the Sylvia Grinnell River char, 1948, 1950 and 1951 (11 specimens were not sexed).

Winters	No.	Average length	Length range	Males		Females	
				No.	Mean length	No.	Mean length
		<i>cm.</i>			<i>cm.</i>		<i>cm.</i>
4	3	9.0	8.5-10.0	1	8.5	2	9.2
5	18	13.0	11.0-14.5	5	13.4	11	12.9
6	7	13.9	12.5-16.5	3	13.7	3	13.3
7	7	17.2	14.5-17.0; 28.5	2	14.5	5	18.5
8	25	30.2	17.0-19.0; 27.0-39.5	8	31.2	17	30.5
9	68	33.7	18.5-20.0; 26.5-46.5	34	33.7	34	33.0
10	68	36.3	26.5-52.0	36	37.1	32	35.4
11	73	41.4	29.5-55.0	34	41.3	39	41.5
12	85	42.5	30.5-57.0	36	42.2	49	42.7
13	96	48.4	30.5-65.0	57	48.5	39	47.5
14	71	51.0	36.0-63.0	40	52.1	30	50.0
15	48	55.3	31.0-67.5	29	58.1	18	51.0
16	38	55.7	44.0-68.5	25	56.9	12	52.5
17	31	55.9	36.5-70.0	22	57.4	9	52.2
18	19	60.0	46.0-70.5	11	61.7	7	56.1
19	23	61.3	46.5-74.0	12	65.6	11	56.6
20	35	64.9	55.0-76.5	17	66.2	16	62.8
21	35	64.2	50.0-76.5	17	66.9	18	61.6
22	19	65.8	44.0-78.5	13	66.3	6	64.6
23	16	67.8	51.0-81.5	11	70.9	3	59.0
24	9	67.8	58.5-78.5	5	69.7	4	65.5
24 plus	12	68.5	51.0-82.5	7	68.2	5	69.0
	806			425		370	

This length gap has been discussed above, where it was concluded that it arose from unrepresentative sampling. The observed length ranges of the sampled 4-, 5- and 6-winter char fall below this gap in the sample.

Figure 12 shows a frequency histogram of the entire 5-winter sample (18 specimens), three of which were taken in salt water (indicated by shaded areas in the figure). The observed length range (11–14 cm.) of the 5-winter freshwater sample, taken in minnow traps, falls clearly within the limits of effectiveness of the traps (8.5–15 cm.). It is probable that the capture, by minnow traps, of specimens well within the range of vulnerable sizes was approximately random, and therefore that the 5-winter specimens taken in this way were representative of this age group in the population. The mean length of these eight specimens is 12.9 cm., the mean length of the entire freshwater, 5-winter sample (15 specimens) is 12.9 cm., and the mean length of the 5-winter sample, taken by all methods, is 13.0 cm. From this it is concluded that the observed mean length of all the 5-winter fish may approximate closely the mean length of this age group in the population at the time of sampling.

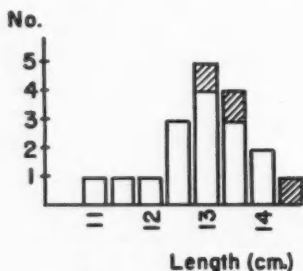


FIGURE 12. Frequency histogram of the 5-winter sample. Shaded areas represent specimens taken in salt water.

The mean length of the 6-winter fish of the sample is 13.9 cm., the length range being from 12.5 to 16.5 cm. This mean is derived from only seven specimens. The frequency distribution is strongly biased in favour of the smaller fish, most being within the minnow trap size limit (15 cm. and less), and as the larger fish (15 and 16.5 cm.) were taken by hand, there is no reason to believe that the maximum size of the 6-winter fish of the population should be limited at 16.5 cm., fish between 15 and 26.5 cm. having been sampled very sparingly. The 6-winter mean of 13.9 cm., therefore, may be expected to be lower than the true mean of the 6-winter fish of the population.

The size range of the 7-winter fish sampled crosses the 20.5- to 26.5-cm. gap in the sampling (Table II, above), with one specimen of 28.5 cm. and six from 14.5 to 17 cm. It is apparent from this that the mean of 17.2 cm. for individuals sampled may well be short of the mean for the 7-winter fish of the population. On similar grounds the 8-winter mean of 30.2 cm., and that of the 9-winter group, 33.7 cm., the length ranges of which overlap the non-sampled size but are

weighted heavily in the upper parts rather than in the lower parts of their ranges, may be considered as being probably higher than the 8-winter and 9-winter means of the population.

The minimum length range of the 10-winter specimens, 26.5 to 49.5 cm., coincides with what has been considered previously as the smallest effective size of the 2½-inch-mesh nets (with one exception, an 18.5 cm. specimen) used in their capture. This makes possible an extension of the range of the 10-winter fish of the population to a smaller size than the sample indicates, thus the mean may be slightly high for the group.

The sampling of the age groups older than 10 winters does not show such obvious faults as those described above, with the result that the means calculated from otolith readings may be considered at least as approximating those of the population.

From this it may be expected that the actual growth curve of the char will approximate the observed curve involving the 5-winter and 11- to 24-winter specimens on the basis of adequate sampling of these, but that it will depart from the points on the observed curve concerning the 6-, 7-, 8-, 9- and 10-winter specimens obtained.

THE RELATIONSHIP BETWEEN OTOLITH GROWTH AND FISH GROWTH

As fishing extended throughout the summer, the growing period of the char, the mean observed lengths, even of suitably sampled age groups, do not suffice to show the true lengths at different ages at a particular time of the year, although in the older, more slowly growing fish the difference may be slight. As sampling did not collect representatives of all age classes (none was taken less than 4 winters) and there is reason to believe that the observed lengths of some of the younger groups differ from the population, due to sampling inadequacies, it was required to construct a calculated growth curve, based upon length at the conclusion of successive winter periods.

Otolith widths were measured, along a line at right angles to the long axis, and these dimensions were related to fish length, to show the mean relationship between fish length and otolith width. In Table III are given mean otolith widths related to fish length. Otolith measurements are given for 195 individuals, and are correlated with average lengths of the fish from which they were taken. Otolith widths are given in units of the micrometer used in making the measurements (one unit equals 0.064 mm.).

The relationship given in Table III is presented graphically in Figure 13. From this it is apparent at once that this relationship cannot be expressed by a straight line, therefore that otolith growth does not proceed at a constant rate relative to fish growth. By plotting otolith widths against fish lengths on double logarithmic paper a straight-line relationship was shown. From this the following equation was derived:

$$\log (\text{fish length}) = -1.503 + 1.982 \log (\text{otolith width}).$$

This curve is plotted in Figure 13, and the mean calculated otolith widths are given in Table III, below.

TABLE III. Otolith width (in 0.064 mm. units) related to fish length (in cm.).

Fish-length group	No.	Mean fish length	Mean otolith width	Calculated otolith width
<i>cm.</i>		<i>cm.</i>	<i>units</i>	<i>units</i>
5-14.5	20	12.7	20.7	20.7
15-24.5	6	17.1	24.7	23.2
25-34.5	26	31.2	31.8	32.5
35-44.5	24	40.1	36.5	36.9
45-54.5	37	50.0	41.5	41.3
55-64.5	33	59.5	44.5	45.0
65-74.5	39	68.9	48.0	48.5
75-84.5	10	80.4	53.5	52.4
	195			

A wide range in otolith size is apparent in various length groups, and is explained by older fish of a given length having larger otoliths than younger specimens of the same length. Molander (1918) found in the herring that older individuals of the same length as younger ones have larger scales. In view of this the equation proposed above must be interpreted as showing only the mean trend of otolith diameter growth as related to growth in fish length, and not as indicating the variation in otolith growth rate which exists among fish of similar length.

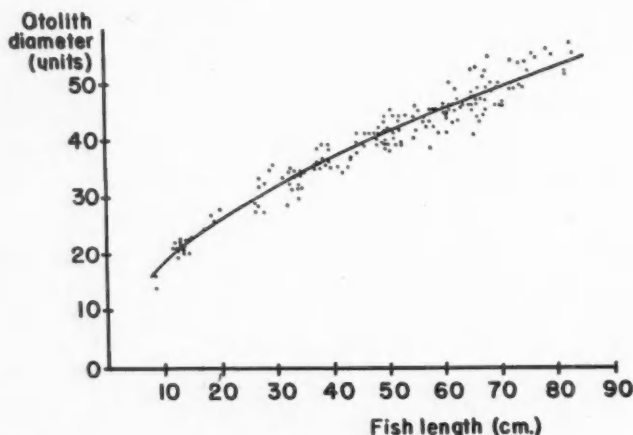


FIGURE 13. The relationship between otolith width and fish length. The dots represent values for individual fish, the curve the mean relationship.

From Figure 13 it is evident that otolith growth is relatively rapid during the early part of the fish's life, and that as fish length increases, otolith growth falls off gradually, the relationship becoming more nearly linear as the fish become larger. Reliability of the curve below the 10-cm. fish-length point cannot be shown from samples available, so use of this portion of the curve in further

calculations must be done with full realization of the possibility of error involved. While no evidence was collected to show the time of formation of the otoliths in the char, extrapolation of the calculated curve suggests the probability of otolith formation taking place while the fish are very small, during the first winter of life, as suggested above.

THE RELATIONSHIP BETWEEN OTOLITH WIDTH AND FISH AGE

In order to measure the relationship between otolith width and fish age, otolith-ring width measurements were made from 313 char (Table IV, below).

It was obviously necessary to make the same otolith measurements in describing both this relationship and that between otolith width and fish length, above, so the greatest widths of rings along a line at right angles to the long axis of the otoliths were used. It became evident that such measurements on all rings could not be made successfully on all the otoliths tried because of lack of clarity in the structure of many of the rings along the required line. Suitable otoliths from 313 char were used in making the ring measurements, one ring diameter, selected at random, being measured in each. This permitted a wide selection of otoliths and a choice of the clearer rings present for measuring purposes. Only otoliths from fish of 10 winters or older were used, in order to eliminate error arising from sampling inadequacies in the younger specimens.

Shown in Table IV are observed mean otolith-ring measurements (expressed in units of 0.064 mm.) at the conclusion of successive winters, and calculated mean otolith-ring widths (in the same units) obtained by fitting a freehand curve to the observed points.

THE CALCULATED GROWTH RATE

The relationships existing between otolith width and fish length and otolith width and fish age having been shown, combination of these results were used to produce a calculated growth rate for the char. In Table V are shown calculated lengths for the ends of successive winters of growth, that is for the times when the depositions of dark rings are completed. These results were obtained from the equation described above:

$$\log (\text{fish length}) = -1.503 + 1.982 \log (\text{otolith width}).$$

The calculated growth curve resulting from the figures in Table V is given in Figure 14, plotted together with the means of the observed fish lengths. Fairly close agreement is shown between the points representing larger fish in both curves. It is seen, however, that for fish of less than 12 winters the deviation in some age groups is considerable. This applies particularly to those sampled from the 8- and 9-winter classes, discussed above as being sampled probably from larger than average fish of the age groups in the population. Those from the 6- and 7-winter groups are seen to be smaller in the sample than in the calculated curve, these being too small for the 4-inch-mesh gill nets, and only small individuals having been collected, in minnow traps and by hand. In agreement with the earlier suggestion that the 5-winter char were sampled fairly adequately is

TABLE IV. Otolith-ring width (in units of 0.064 mm.) related to fish age.

Winters	Observed mean otolith-ring width	Calculated mean otolith-ring width	Number of otoliths
1	4.9	4.9	12
2	9.3	9.1	12
3	12.9	12.9	12
4	16.3	16.4	12
5	19.6	19.7	12
6	22.8	22.8	12
7	25.6	25.7	12
8	28.1	28.5	11
9	31.2	31.2	11
10	33.9	33.7	16
11	36.0	36.0	14
12	38.1	38.1	11
13	40.1	39.9	24
14	41.3	41.4	24
15	43.3	42.7	15
16	43.5	43.8	16
17	44.0	44.7	12
18	45.0	45.4	8
19	46.1	46.1	14
20	46.9	46.7	16
21	47.0	47.2	17
22	47.6	47.6	7
23	48.2	48.0	10
24	48.7	48.4	3
			313

TABLE V. Calculated lengths for various ages of the char, compared with observed lengths.

Winters	Mean observed fish length	Mean calculated fish length
	<i>cm.</i>	<i>cm.</i>
1	.....	1.4
2	.....	2.5
3	.....	5.0
4	9.0	8.0
5	13.0	11.6
6	13.9	15.4
7	17.2	19.6
8	30.2	24.0
9	33.7	28.5
10	36.3	33.5
11	41.4	38.2
12	42.5	42.7
13	48.4	46.8
14	51.0	50.3
15	55.3	53.5
16	55.7	56.3
17	55.9	58.6
18	60.0	60.4
19	61.3	62.3
20	64.9	63.9
21	64.2	65.3
22	65.8	66.4
23	67.8	67.5
24	67.8	68.6

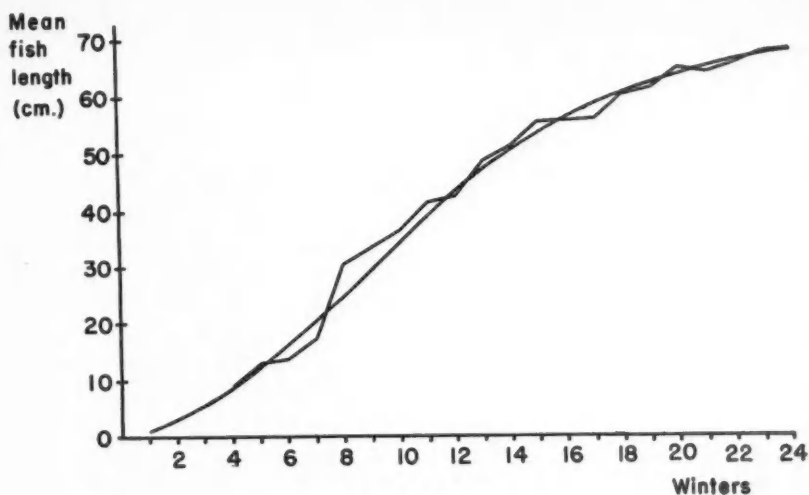


FIGURE 14. The observed and calculated growth curves. The smooth line shows the calculated growth curve of the population.

the closeness of the observed and calculated curves as they apply to this group. The end-of-winter lengths of the fish younger than four winters, as indicated by calculated lengths, are not supported by any observed fish lengths, and have been calculated by extrapolation from the fish length-otolith width curve.

In Figure 15 yearly growth increments are shown, lengths being given for the ends of successive winters, from the conclusion of the first to the twenty-fourth.

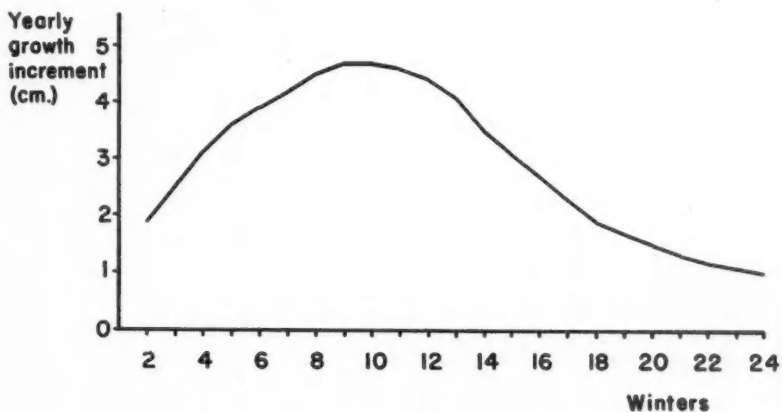


FIGURE 15. Yearly length increments in growth, taken from the calculated growth curve of the population.

From this it appears that length increase, relative to the preceding year's, is successively greater until the end of the ninth winter, after which the yearly length increment decreases. The summers of greatest growth are the eighth and ninth.

It is obvious that a calculated growth curve such as this, even if it succeeds in approximating the mean growth of the population, does not make altogether clear the growth of this fish. The range of sizes of different age groups has been shown to be large, with the result that 60-cm. fish, for example, are found in all age groups between 13 and 24 winters. This is due partly to the slow growth of the char, which gives time for the establishment of a wide range in length, and probably also to a variation in growth associated with different lengths of time spent in fresh water before the fish make their first migration to the sea. Dahl (1926) showed that the char of Svalbard which migrate after only two winters in fresh water reach a substantially greater length than those which remain three or four years in fresh water before migrating to the sea for the first time.

SEX DIFFERENCES IN THE GROWTH RATE

The mean fork length of males for the three seasons' fishing was 52.3 cm., of females 49.2 cm. The superiority in numbers of males over females sampled appears in the fish of about 55 cm. and longer, while more females than males were taken between 45 and 55 cm. In the smaller fish no apparent difference in numbers exists.

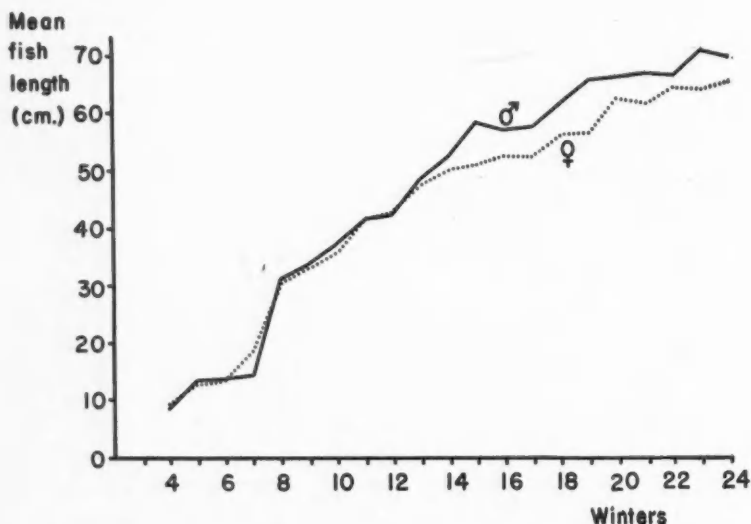


FIGURE 16. The growth curves of males (—) and females (....), taken from the observed lengths of the sample.

Given in Table II are the observed lengths of 425 males and 370 females from which age determinations were made. The observed age-length relationships of males and females are plotted in Figure 16. From these curves there is little evidence of a length difference before the completion of 12 winters, after which a noticeable divergence between the growth of the sexes appears, the males being distinctly larger in all age groups. This suggests that while during the first half of the lifetime of the char no appreciable length difference is evident between the sexes, after about 12 winters the males surpass the females in rate of growth, exceeding them in mean length by some 5 cm. in the oldest fish. This establishment of a difference in the growth rate between males and females after 12 winters of growth coincides with the probable mean age of sexual maturity being reached in the females, discussed below.

WEIGHT OF THE CHAR

Total fresh weights were taken of 693 char in the field during the 1951 season, using a scale graduated in tenths of pounds. In Table VI are shown weights compared with lengths of fish, averaged for both sexes and for each sex separately, for the entire fishing period, and for the periods June 26 to July 23 and July 24 to September 5. Average weight measurements are given for 5-centimetre length groups, of fish from 25 to more than 75 cm. fork length. Fish smaller than 25 cm. in length were not weighed, the scale graduations being too large to permit the required accuracy of measurement.

This comparison between the weights of males and females for the entire season shows little difference between the sexes in any of the size groups, except for the 75- to 79.5-cm. sample which is small. The weights of the fish taken from June 26 to July 23, compared with those from July 24 to September 5, indicate a substantial increase in weight in almost all length groups between the first and second periods. These data are shown graphically in Figure 17, the upper curve showing weights during the July 24 to September 5 period, the lower curve the June 26 to July 23 period.

Such an increase in weight may be attributed to at least two factors: enlargement of gonads and improvement in the general condition of the fish. While the gonads of both sexes showed an increase in size during a part of the summer season, the difference in weight indicated by these figures is well in excess even of the maximum gonad weight found in 1951. It is probable, therefore, that an improvement in the condition of the fish took place towards the end of the summer period in the sea, as a result of the rich food supply available during the summer in salt water.

The weights of 506 char are compared in fish from 9 to 24 winters, and conspicuous sexual differentiation is shown. In Table VII weight averages for males, females and both sexes combined are given for ages combined in two-winter groups. The weight increase with age of 264 males and 242 females is presented in Figure 18. This shows a distinct weight superiority in males over females from the 13-14 winter group on, which was approximately the age at which males were

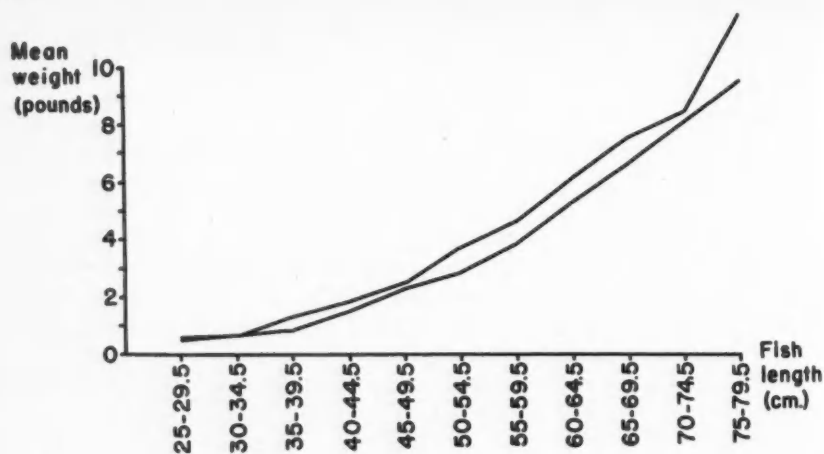


FIGURE 17. The relationship between fish weight and length shown for the period June 26 to July 23, by the lower curve, and for the period July 24 to September 5, by the upper curve.

shown to exceed females in length, above. Here, as in the age-length comparison, no appreciable difference is revealed between males and females of less than about 12 winters.

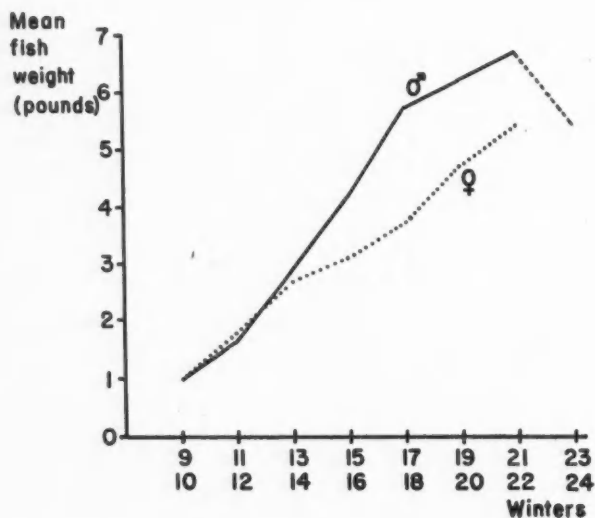


FIGURE 18. Mean weights of males and females in the different age groups.

TABLE VI. Weights based on fish length, for the entire 1951 season, and for the periods from June 26 to July 23 and July 24 to September 5.

Length group	Entire season 1951					
	Total		Males		Females	
	No.	Av. wt.	No.	Av. wt.	No.	Av. wt.
<i>cm.</i>		<i>lb.</i>		<i>lb.</i>		<i>lb.</i>
25-29.5	37	0.5	16	0.5	21	0.5
30-34.5	103	0.6	54	0.6	49	0.6
35-39.5	81	1.1	39	1.0	42	1.1
40-44.5	72	1.7	33	1.7	39	1.7
45-49.5	121	2.4	59	2.4	62	2.4
50-54.5	113	3.3	65	3.3	48	3.3
55-59.5	88	4.4	55	4.3	33	4.5
60-64.5	50	5.8	29	5.8	21	5.8
65-69.5	17	7.2	9	7.2	8	7.2
70-74.5	7	8.4	7	8.4	0	...
75-79.5	4	10.2	3	10.2	1	8.4
June 26-July 23, 1951						
25-29.5	14	0.4	7	0.4	7	0.4
30-34.5	27	0.6	15	0.6	12	0.6
35-39.5	37	0.8	19	0.8	18	0.8
40-44.5	22	1.5	7	1.4	15	1.6
45-49.5	45	2.3	21	2.2	24	2.4
50-54.5	46	2.8	26	2.7	20	2.9
55-59.5	26	3.8	16	3.7	10	3.9
60-64.5	16	5.3	9	5.2	7	5.4
65-69.5	6	6.6	5	7.1	1	4.5
70-74.5	...	...	0	...	0	...
75-79.5	2	9.5	1	10.7	1	8.4
July 24-September 5, 1951						
25-29.5	23	0.6	9	0.6	14	0.6
30-34.5	76	0.6	39	0.6	37	0.6
35-39.5	44	1.3	20	1.2	24	1.3
40-44.5	50	1.8	26	1.8	24	1.8
45-49.5	76	2.5	38	2.5	38	2.4
50-54.5	67	3.7	39	3.7	28	3.6
55-59.5	62	4.6	39	4.5	23	4.7
60-64.5	34	6.1	20	6.1	14	6.0
65-69.5	11	7.5	4	7.3	7	7.6
70-74.5	7	8.4	7	8.4	0	...
75-79.5	2	11.9	2	11.9	0	...

TABLE VII. Weight related to age of the char.

Age group	Both sexes		Males		Females	
	No.	Mean weight	No.	Mean weight	No.	Mean weight
<i>winters</i>		<i>lb.</i>		<i>lb.</i>		<i>lb.</i>
9-10	122	1.0	62	1.0	60	1.0
11-12	136	1.8	61	1.7	75	1.8
13-14	129	2.8	75	2.9	54	2.7
15-16	61	2.8	37	4.2	24	3.1
17-18	29	5.0	20	5.6	9	3.7
19-20	14	5.1	4	6.2	10	4.7
21-22	14	5.8	4	6.7	10	5.4
23-24	1	5.4	1	5.4	0	...
	506		264		242	

GROWTH OF THE ARCTIC CHAR OF BAY OF TWO RIVERS,
GEORGE RIVER AND HERSCHEL ISLAND

In addition to the collection of char from the Sylvia Grinnell River, small samples were obtained from three other regions: Bay of Two Rivers, about 15 miles southwest of the Sylvia Grinnell, in Frobisher Bay; George River, on the southeast shore of Ungava Bay, Quebec; and Herschel Island, N.W.T. Specimens from these three locations were collected respectively by John Wright in 1950, by M. J. Dunbar in 1951, and by A. H. Lawrie in 1951.

The Bay of Two Rivers sample included 16 fish from which age determinations were made. They were captured in gill nets set near the mouth of a pair of rivers which flow into northwestern Frobisher Bay. While it cannot be said at present whether these fish constitute a population distinct from those of the Sylvia Grinnell, their point of capture was in closer proximity to several apparently suitable char streams than to the Sylvia Grinnell River. Fishing was done in this area between August 20 and 27, 1950. The average fork lengths of age groups from 11 to 23 winters are given in Table VIII.

TABLE VIII. Age and length of the Bay of Two Rivers char, 1950.

Winters	No.	Mean fork length <i>cm.</i>	Length range <i>cm.</i>
11	2	48.5	48.0-49.0
12	0	....	....
13	3	54.0	47.0-61.5
14	1	59.0	....
15	0	....	....
16	1	66.0	....
17	2	64.5	61.5-67.5
18	1	65.0	....
19	4	69.0	67.5-70.5
20	0	....	....
21	0	....	....
22	1	64.5	....
23	1	74.5	....
—		16	

The George River char were fished on July 23, 1951, in fresh water. Age determinations were made on 10 specimens, all falling in the 7-, 8- and 9-winter groups. Average fork lengths are shown in Table IX.

TABLE IX. Age and length of the George River char, 1951.

Winters	No.	Mean fork length <i>cm.</i>	Length range <i>cm.</i>
7	6	40.8	37.5-43.5
8	2	43.7	43.5-44.0
9	2	43.5	42.5-44.5
—		10	

The sample from Herschel Island was obtained from gill nets in salt water on August 17, 18 and 19, 1951. Fifteen fish showed ages from 4 to 11 winters, as given in Table X. Standard lengths are given.

TABLE X. Age and length of the Herschel Island char, 1951.

Winters	No.	Mean standard length	Length range
		cm.	cm.
4	1	20.1	.....
5	3	25.5	21.8-27.4
6	1	33.2	.....
7	2	37.3	36.9-37.8
8	2	39.0	38.9-39.2
9	3	38.6	35.9-40.0
10	1	48.1	.....
11	2	51.1	50.0-52.0
	15		

The age-length relationships of these three samples are shown in Figure 19, compared with the calculated Sylvia Grinnell population growth curve. As the Bay of Two Rivers sample was taken in the sea late in August, and only large-mesh gill nets were used, the apparent length differences of these few specimens from the Sylvia Grinnell char may be exaggerated. All the specimens fall within the length range of the Sylvia Grinnell sample. A real difference between the George River and Herschel Island char, and those of the Sylvia Grinnell does seem to exist, however. As the measurements of the Herschel Island sample are given in standard length, and fork length would mean an increase of roughly 2 to 3 cm., both these and those from George River fall well above the length range of the Sylvia Grinnell char of comparable age. There is a strong suggestion of a more rapid growth rate in both the Herschel Island and George River populations than in that of Frobisher Bay, at least the Sylvia Grinnell River.

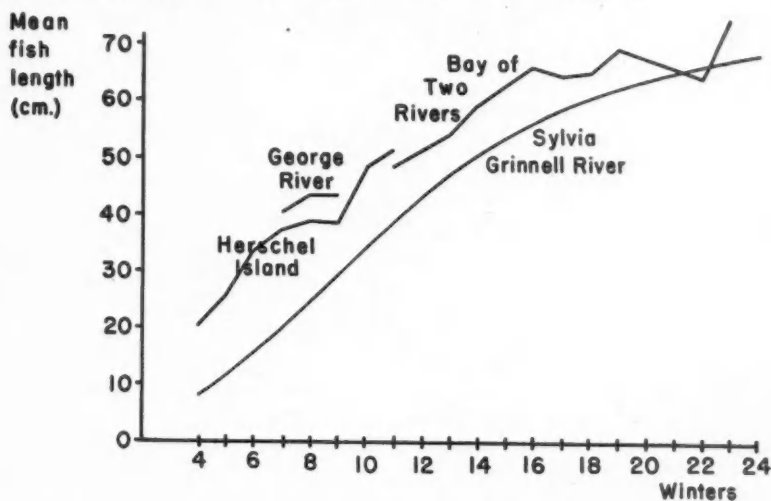


FIGURE 19. Comparison of the growth curves of the Sylvia Grinnell, Bay of Two Rivers, George River and Herschel Island samples. The Herschel Island lengths are expressed as standard length, the others as fork length.

GROWTH OF THE ARCTIC CHAR IN SVALBARD AND WEST GREENLAND

Age determinations of 84 specimens of the Arctic char of western Svalbard were carried out by Dahl (1926) on material collected in August, 1923, at the mouth of a river from Lake Dieset, and at Cape Starostin. Scales were used in this study, but "presented . . . certain difficulties mainly due to the minute size of the scales. The various summer and winter zones could, as a rule, be read with fair accuracy, except in the case of some of the largest and oldest fish." Scales were taken from fish of 20 to 72 cm. in length. The following age-length relationship of the sea-run char was constructed from Dahl's data on observed lengths.

<i>Winters</i>	<i>No.</i>	<i>Av. length (cm.)</i>
3	2	24.5
4	9	34.0
5	23	36.9
6	19	41.2
7	11	48.3
8	9	53.3
9	6	61.1
10	4	67.0
11	1	70.0
	84	

In addition to these anadromous char from Svalbard, Dahl reported the ages of a small number of char from Novaya Zemlya. One small specimen, 5.4 cm. long, had no readable scales, while another, of 5.8 cm., showed two to three growth rings. From Lommevand at Matoschkin, Novaya Zemlya, three fish, 18, 19 and 20 cm. in length, showed 4, 4 and 5 winters of growth respectively. These displayed no evidence of having been to sea, and appeared to be in spawning condition for that year. Also from the same area, but taken in the sea, was a 48 cm. male with 4 parr winters and 2 winters after migration showing on its scales.

In 1937 and 1939 otoliths from 671 anadromous char were collected in western Greenland by Paul Hansen (1940). The otoliths were used in age estimation and a maximum age of about 20 years was suggested. Fishing was carried out at the following stations: Kobbefjorden, Godthaab, June 28-29, 1937; Tylorshavn, Frederikshaab, July 22, 1937; Kangermiutsiait, Julianehaab, August 4, 1937, and August 8-9, 1939; Itivdlek, in Bredefjord, Julianehaab, August 10-11, 1939; and Kugssuak, in Tasermiutfjord, Julianehaab, August 25-28, 1939.

From these stations the following average lengths for age groups were recorded.

<i>Station</i>	<i>Year</i>	<i>Age in years</i>							
		4	5	6	7	8	9	10	
Kobbefjorden	1937	....	....	....	....	....	43.0	48.0	
Tylorshavn	"	19.0	20.1	23.7	27.5	26.8	....	....
Kangermiutsiait	"	....	....	34.2	35.6	....	....	....
"	1939	....	22.4	25.5	31.0	34.4	35.9	37.4	
Itivdlek	"	....	....	....	....	42.1	45.5	48.9	
Kugssuak	"	....	....	....	....	52.5	54.0	55.4	
<i>Station</i>	<i>Year</i>	<i>Age in years</i>							
		11	12	13	14	15	16		
Kobbefjorden	1937	48.9	51.9	53.0	....	53.6	....	
Tylorshavn	"	....	....	....	....	....	....
Kangermiutsiait	"	....	....	....	....	....	....
"	1939	....	....	....	....	....	....
Itivdlek	"	49.7	53.0	53.5	....	54.5	....	
Kugssuak	"	57.1	55.0	60.6	60.2	....	66.8		

A comparison between the data on growth rate of the Svalbard, western Greenland and Sylvia Grinnell anadromous char suggests differences in the rate of growth in all three regions. That the char of Svalbard grow at a faster rate than those of Frobisher Bay is highly probable, the length averages of the Svalbard sample falling entirely outside (above) the maximum length range found in Frobisher Bay. Also maturity of the anadromous Svalbard char is known to occur in fish of 5 winters (Dahl, 1926), in much younger fish than in Frobisher Bay. It is difficult to compare the results from Greenland, which vary so among themselves, with the growth of the Svalbard and Sylvia Grinnell char. All the mean-length values of the Greenland samples fall between the mean lengths of the Svalbard and Sylvia Grinnell fish of comparable ages.

MIGRATION

The movements of migrating Arctic char conform to a general pattern throughout the parts of its range where migratory movements have been noted, in that the descent to salt water occurs usually at about the time of ice break-up in the spring or early summer, and the ascent into freshwater streams takes place in the late summer or early fall.

Mass downstream movements of the char of the Sylvia Grinnell River have not been observed by the author. The ice covering of the river broke just before June 10, 1951, and at that time only a small number of small fish was observed in the river, descending to the sea. With the first use of nets below the river mouth, immediately after the ice had cleared sufficiently from the river-mouth area to permit the use of nets, large fish were taken which evidently had entered the sea earlier. They were well fed and appeared to be in good condition. At this time the occasional small fish still was descending the river falls.

It would seem that the entrance of the larger fish into the sea precedes that of at least some of the smaller ones, and that it may occur in the spring before the break-up of the ice about the river mouth, that is under the ice. Although a thick ice covering forms over the Sylvia Grinnell River during the winter, unfrozen water is present at all times below it. Breaking up of the surface ice, therefore, need not occur in order to permit the fish to gain access to the sea.

It is not known whether any of the Sylvia Grinnell char spend the winter in the sea. The local Eskimos say they do not. Evidently they have taken none in the sea during the winter, while they have caught the char in the winter in the lake in which they are said to spend the winter.

Evidence for upstream movement in the Sylvia Grinnell River suggests that variations in the time of river ascent may be expected in different years. The conditions at the mouth of the Sylvia Grinnell are perhaps different from most char streams in that there is the necessity for the char to ascend a waterfall to gain access to the fresh water above. Near the mouth of the river, in the salt water, fish movements undergo periodic changes dependent upon the condition of the tide. During the time following migration of the fish to the sea, the incoming tides are accompanied by char which move as far upstream as the falls, then, with the falling tide, withdraw into the bay. Even after upstream migration begins many fish continue to return to the bay as the tide falls. These movements are

readily apparent, particularly when the water is calm. Great numbers of the fish may be seen moving in with the tide, some jumping almost clear of the water, others breaking the surface with their dorsal fins and backs, almost all headed towards the falls. With the turn of the tide they reverse their direction of movement, and return to the bay, showing themselves again by frequent breaking of the water surface. The presence of the falls at the river mouth influences clearly the movements of these fish, in providing during much of the time a substantial barrier to the river.

The Arctic char do not seem to possess the jumping qualities of the Atlantic salmon found to the south. None was seen to succeed in ascending the falls at low tide, although on several occasions char were observed to leap upwards into the falls when the water was low, but at no time did they rise more than a few feet and they were always forced back into the water at the base of the falls. To gain access to the fresh water, headway must be made against a strong flow even at the best of times, that is when the tides are highest, and it is during the periods when the height of the falls is at its minimum that most upstream movement of the char takes place.

Spring tides occur twice each month, and it is at these times that the upstream movement takes place most abundantly. In 1951 the spring tides of the first week in August coincided with the first evidence of mass upstream movements of the fish. River ascent in 1950 began earlier than in 1951. The char were reported ascending the river at the end of July, and this time agrees with that of spring tides, which occurred during the last week of July. For 1948 precise data are not available on the time of the upstream run. Some ascent of the river occurred in late July, but relatively little upstream movement was noticed until the first week in August. Spring tides occurred at this time and were accompanied by what was probably the first large-scale upstream movement.

Females exceeded males in number in the 1948 sample; in 1950 and 1951 there were more males than females, but the ratios differed considerably (see Table I). During each of the three seasons of fishing more females than males were taken during the two to three weeks immediately preceding the commencement of upstream migration. Shortly after the migration began more males than females were observed. This suggests the possibility of the females ascending the river before the males. In 1948, when the sex ratio was 173 males to 203 females, 294 specimens were observed before and only 82 after upstream migration began. In 1950 the sex ratio was 150 males to 103 females, and only 42 fish were examined before and 211 after the beginning of upstream migration. In 1951 the sex ratio was 452 males to 406 females, and approximately the same number of fish were taken before as after upstream migration began.

The 1948 sex ratio favouring females may be attributed at least partly to the time of fishing which coincided with an abundance of females in the fishing area. The pronounced abundance of males in the 1950 sample may be due to fishing having occurred at a later time, most of it having followed the beginning of migration when more males than females were present in the region of fishing. Fishing in 1951 took more females than males during the period coinciding with

most of the 1948 fishing season, more males than females during the time coinciding, with respect to migration time, with most of the 1950 fishing period.

While this does not preclude the possibility of yearly variation in the sex ratio, it does point out that the ratio of males to females, at least for the 1948 and 1950 samples, cannot be interpreted as showing the sex ratio of the population, because of the apparent movements at different times of the males and females. A slight variation from year to year in the sex ratio of the char may be expected in view of the situation which has been described for other anadromous salmonids. Pritchard (1937) in a four-year study of the pink salmon (*Oncorhynchus gorbuscha*) of British Columbia found significantly more females in one year, more males in another and no statistical difference in the sex ratio in the other two seasons, among migrating salmon.

Whether migration of the Sylvia Grinnell River char takes place every year or not cannot be stated with certainty. There is no evidence of any char having been taken in the sea in winter, and at the conclusion of the autumn migration to fresh water the Eskimo fishery in the sea and about the river mouth is concluded. Also whether char which have been to the sea are to be found in fresh water in the summer is not known.

Dahl (1926) from 84 scale observations was able to estimate the age of the first migration to the sea in the char of Svalbard by the presence in the scales of an abrupt increase in the size of the rings, occurring after the laying down of two winter rings (43 per cent of the sample), three winter rings (50 per cent), and four winter rings (7 per cent). From this he concluded that the first migration occurs after the second and before the fifth winter, probably in all cases before the char reach 20 cm. in length.

Regarding the time of first migration to the sea of the Sylvia Grinnell char there are grounds for concluding that migration occurs at various ages, from at least 5 to 7 winters. As pointed out above, no evidence of the first migration could be found in the otoliths examined. Only three 4-winter fish were taken, in July and August, all in fresh water and with parr markings. Of the eighteen 5-winter specimens, 15 were obtained in fresh water in July and August, and three were taken in salt water. The fish from fresh water ranged in length from 11.0 to 14.5 cm. (average 12.9 cm.), while those taken in salt water were from 13.0 to 14.5 cm. (average 13.8 cm.). None of the salt-water specimens (5-winter) was longer than the largest specimen from fresh water, and all were taken before July 23. The similarity of the lengths of these fish to the non-migrants of the same age suggests that they had migrated in the summer of their capture. All showed parr markings. Of the seven 6-winter specimens taken, five were collected in fresh water during July and August, and two were obtained in salt water. The freshwater fish were 12.5 to 15.0 cm. in length (average 13.6 cm.) and all showed parr markings. One of the salt-water fish was collected in the middle of July, was 13 cm. long and had parr markings. The other, 16.5 cm. in length, was taken on August 11, was considerably longer than any others of the age group, and showed no parr markings. While the first of these evidently had migrated after its sixth winter, the second probably had moved first to the sea at an earlier age. Seven

7-winter char were collected, five in fresh water during July and August, from 14.5 to 16.5 cm. long (average 15.0 cm.), all with parr markings, and two in salt water, one of 17.0 cm., the other of 28.5 cm. length. The latter two specimens were obtained at the end of August, and it is probable that the 28.5 cm. specimen had migrated at an earlier age than the 17.0 cm. char. Twenty-five 8-winter fish were observed, all in salt water, and all but two were 27 cm. or longer. Two small specimens, 17 and 19 cm. long, were taken, the former ascending to fresh water at the end of August. The explanation for the size gap in this sample has been discussed above. It is probable that the two small specimens had migrated first at a greater age than the others, possibly as late as seven winters.

It is to be expected that such a slowly growing fish as the Arctic char, which lives more than 24 years, should show a considerable size range within single year classes, as revealed in Table II. In the sample studied, however, there is no great increase in the size range of age groups with increase in age after the eighth winter. In the discussion of sampling, above, it was concluded that the 5-winter group was sampled to show the full freshwater range of this class. From the location of capture of the 4-winter specimens and the lengths of the 5-winter fish taken in salt water there is no evidence of migration occurring previous to the fifth winter. It appears that most of the variation in the growth rate occurs between the fifth and eighth years, during which time most of the first movements to the sea evidently take place.

The first entrance of anadromous fish into the sea usually is accompanied by an increase in the growth rate. This has been described by many workers, among them Dahl (1926), referred to above. This means that if the first migration to the sea occurs over several years in different individuals, the length range of the population increases rapidly within the age groups migrating for the first time. The establishment of such a range as this in the char of the Sylvia Grinnell because of first migration occurring in at least the 5-, 6- and 7-winter fish is probable, and would explain the development of this large length range within three years. Evidence for this in the Frobisher Bay char has not been discovered in the growth of individual fish, nor has it been shown by the calculated growth curve of the population. Such an increase in the growth rate, however, would be obscured in the population growth curve, if it occurs over a period of several years.

There seems to be a definite tendency for the char of Frobisher Bay to remain close to the river mouths throughout the summer. This applies to all size groups, but most particularly to the small fish, which in 1951 were present at all times during the entire summer about the base of the Sylvia Grinnell falls, and were taken only rarely at points in the fishing area away from the falls. The tendency for fish of all sizes to linger near the river mouths is shown by the carrying out of successful fishing in close proximity to the rivers long after seaward migration is completed and before the return to fresh water begins.

EGG SIZE AND FECUNDITY

As part of the field work done on the char of the Sylvia Grinnell River in 1950 and 1951 observations were made on ovaries, and samples were brought to the laboratory for examination. From the field observations on the ovaries it was

evident that at least two size groups of eggs were present in many of the fish, this being readily apparent in the fish with the largest eggs. One group contained large eggs, yellowish in colour, the other small, white eggs. The diameters of the large eggs exceeded 4 mm. and were rarely less than 3 mm., while the diameters of the small eggs were all less than 2 mm. In the smaller fish no such clear differentiation existed, all the eggs being small and white.

The finding of eggs of two or more size groups is a common occurrence in fish during the period preceding spawning (Hickling and Rutenberg, 1936; Carbine, 1943). In the fish which spawn once a year a number of the eggs within the ovaries begin to enlarge previous to the spawning time. They acquire a quantity of yolk and become distinctly set apart from the remaining eggs, which remain small and immature. It is apparent that the differentiation in the eggs of the char is of this kind, the larger eggs being those which are in the process of maturing for the spawning period in the autumn, the smaller eggs being immature, destined not to mature that fall.

The measurements made of egg diameters of the char were of only the maturing eggs when they were present, the immature eggs being measured only when no maturing eggs were observed, that is when the immature eggs were the largest eggs present. The measurements of egg diameters done in the field were of one egg only in each of 165 fish sampled, and were expressed to the nearest millimetre. These were done in 1951. The measurements made in the laboratory, of the eggs of 185 fish, were done in a more precise fashion. Five eggs were picked from various parts of the ovaries of each fish and were measured, using an ocular

TABLE XI. Frequency of egg diameters, 1950 and 1951, in units of 0.064 mm.

Egg diameter	No.
<i>units</i>	
2-6.9	7
7-11.9	5
12-16.9	20
17-21.9	45
22-26.9	47
27-31.9	20
32-36.9	1
37-41.9	4
42-46.9	4
47-51.9	7
52-56.9	8
57-61.9	8
62-66.9	5
67-71.9	4
	185

micrometer. The mean of the five readings was used, and was expressed as units of the micrometer (one unit equals 0.064 mm.). Of the 185 specimens, 10 were collected in 1950, 175 in 1951.

Given in Table XI are the frequencies of egg sizes obtained from the samples measured in the laboratory, taken from fish of 8.5 to 75 cm. in length. Shown by

the table is the small number of fish with eggs just over 30 units (about 2 mm.) in diameter, compared with those with smaller and larger eggs.

In Figure 20 are five frequency histograms of egg diameters, the first four representing two-week periods, the fifth a 17-day period, of the 1951 fishing season. In Period (1) (June 26 to July 9) the largest of the eggs from 23 fish were 44.4 units (2.8 mm.) in diameter, and the differentiation of the eggs into two size groups is not evident. This sample was taken from $5\frac{1}{2}$ to $3\frac{1}{2}$ weeks before

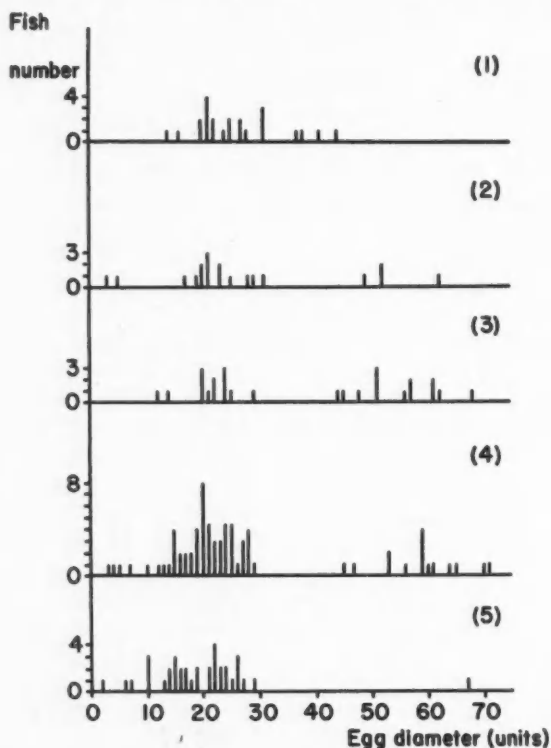


FIGURE 20. Development of the maturing eggs during the summer of 1951. Explanation in text.

upstream migration began. In Period (2) (July 10 to July 23) of the eggs from 19 fish the largest were 62.6 units (4 mm.) in diameter and an interval of 18 units (1.1 mm.) exists between the large (maturing) and the small (immature) eggs. The average diameter of the eggs from the four maturing fish was 54.2 units (3.4 mm.). This period ended about $1\frac{1}{2}$ weeks before the beginning of migration. In Period (3) (July 24 to August 6) the eggs from 26 fish were measured. Two distinct size groups appear, the mean diameter of the maturing eggs being 54.9 units (3.5 mm.). During the latter part of this period upstream migration

began. In Period (4) (August 7 to 20) the eggs from 73 fish were measured, two size groups of eggs appear, and the mean diameter of the maturing eggs was 59.1 units (3.8 mm.). This period extended over two weeks after the beginning of migration. In Period (5) (August 21 to September 5) measurements were made on the eggs of 36 fish, and only one specimen with maturing eggs was found, having eggs with a mean diameter of 67.5 units (4.3 mm.). Coinciding with this period was an apparent reduction in the number of larger females in the fishing area, referred to above.

This series of histograms demonstrates that growth in the size of the eggs occurred during the first half of July, during which time those eggs which were to mature for the next spawning period became differentiated from the other eggs destined to remain immature. By about the middle of July the two types of eggs were clearly distinguishable by size. The growth of the maturing eggs probably continued throughout the rest of the pre-spawning period, but there is no suggestion from these data of any noticeable growth in the immature eggs occurring during the summer.

In Figure 21 the diameters of the eggs of 185 fish are plotted against fish lengths. Clear distinction shows between the maturing and immature eggs. (The five encircled points represent eggs from the four partially matured ovaries of early July, 1951, shown in Figure 20 (1), and one specimen from early in the 1950 season.) There is evidence of a correlation between fish length and the diameter

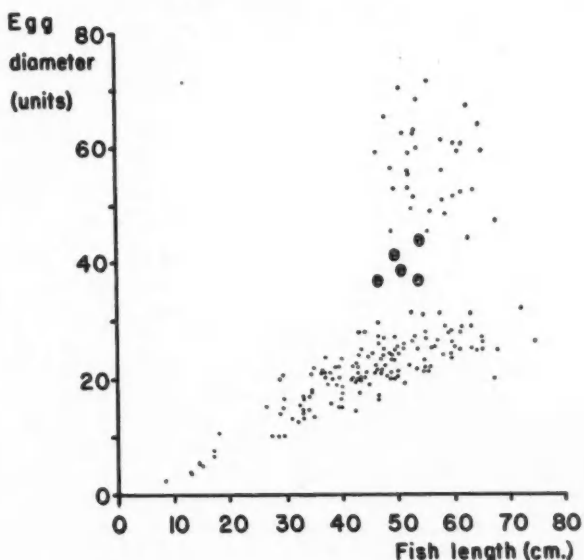


FIGURE 21. Egg diameter compared with fish length. The dots below the encircled points represent immature eggs, those above, maturing eggs.

of the immature eggs, in that egg diameter increases with the length of the fish. This relation is also shown in Table XII.

TABLE XII. The relation between fish length and immature egg diameter (in 0.064-mm. units).

Fish-length group	Average egg diameter
<i>cm.</i>	<i>units</i>
5-9.5	2.6
10-14.5	4.3
15-19.5	7.3
20-24.5	...
25-29.5	14.6
30-34.5	16.1
35-39.5	19.8
40-44.5	20.8
45-49.5	23.1
50-54.5	24.7
55-59.5	25.9
60-64.5	27.6
65-69.5	24.7
70-74.5	29.5

With regard to the maturing eggs no such obvious relationship exists. In order to determine whether a correlation exists between fish length and the size of mature eggs a collection would have to be made at the spawning time.

In at least some of the char which have achieved a length of more than 45 cm. a portion of the eggs has undergone rapid development and commenced to mature. The length at which maturity is reached seems to be approximately 45 cm. in this sample. No maturing eggs were taken from fish less than 45 cm. in length, while in those exceeding this length maturing eggs were found in about 33 per cent of the specimens. Maturing at 45 cm., the females of the *Sylvia Grinnell* are somewhat larger at maturation than the female char of Svalbard, where Dahl (1926) found a mature female of 38 cm.

Table XIII shows the number of maturing and immature specimens in different length groups from 1951, based upon the examination of eggs from 340 specimens.

It is apparent that all the females within the size range of maturity do not spawn every autumn. For the fish of 45 cm. length and greater the ratio of maturing to immature specimens was about 1:2. From only nine measurements made on the eggs of the 1950 sample taken from fish greater than 45 cm. in length, three were maturing and six were immature, a ratio of 1:2.

There is little information available on the spawning frequency of the Arctic char. Yessipov (1935) suggested that the char of Novaya Zemlya spawn in lakes every second year. Jensen (1948) reported of the migrating char of western Greenland, that on July 30, 1909, at Tunugdliarfik Fjord, a number of individuals caught in a river had eggs up to 1 mm. in diameter and were in the company of others which had mature gonads; all were migrating into fresh water. Jensen concluded that unripe females probably ascend the streams with sexually mature

individuals. This situation apparently is similar to what is found in Frobisher Bay, and suggests that spawning is not an annual autumn occurrence in each fish.

TABLE XIII. The number of maturing and immature females taken in 1951.

Fish-length group	Number of specimens		Total
	Maturing	Immature	
<i>cm.</i>			
5-9.5	0	1	1
10-14.5	0	4	4
15-19.5	0	4	4
20-24.5	0	0	0
25-29.5	0	25	25
30-34.5	0	60	60
35-39.5	0	41	41
40-44.5	0	41	41
45-49.5	10	45	55
50-54.5	19	31	50
55-59.5	15	17	32
60-64.5	11	9	20
65-69.5	2	4	6
70-74.5	0	1	1
	57	283	340

The time of spawning of the *Sylvia Grinnell* char is not known definitely. Eskimos of the region say that it takes place in the fall and this is probable from the condition of the gonads in late summer. Various reports on the probable spawning time of the char in other parts of its range indicate that it occurs for the most part in the autumn. An exception to this was reported by Weed (1934) who believed, from gonad observations, that some of the char of Labrador spawn earlier than the usual late autumn spawning time, from the finding on July 13 and 14 of char with free eggs in their oviducts, a great distance from the usual spawning grounds.

Age determinations were done on 126 of the 185 specimens from which egg measurements were made. Of these one fish was found to be maturing at 10 winters, but this specimen was 52 cm. long, considerably larger than the mean for the 10-winter fish in their tenth summer which is about 35 cm. No maturing fish were found at 11 winters, but three were observed at 12 winters. As a length of somewhat over 45 cm. coincides with the mean length of the fish during their twelfth summer, it seems that maturity is reached most commonly after the twelfth winter, at a considerably greater age than that reported for the char in other parts of its range. Dahl (1926) found the first sign of maturity in the Svalbard char in a female of 5 winters. Saemundsson (1927) suggested that the char of Iceland probably are mature at 6 years. Yessipov (1935) found that maturity was reached in the sixth or seventh year in the char of Novaya Zemlya.

Counts of maturing eggs were made from 23 *Sylvia Grinnell* char. Actual counts were done on the eggs of three fish and calculated counts were made on all 23. The method of making the calculated counts was as follows. Ovaries were removed from the fish and superficial ovarian tissue was cleared. Three samples

of eggs, each about 2 to 3 cubic centimetres in bulk, were removed from different parts of the ovaries. These were immersed in water and the displacement of each sample was measured. Counts then were made on the number of eggs in each of the three samples, and the number of eggs per cubic centimetre of ovary was computed. The remaining eggs then were immersed and the amount of water which they displaced was measured. Using the total water displacement of the ovarian eggs in cubic centimetres and the number of eggs per cubic centimetre of ovary, the total number of eggs in both ovaries was calculated.

Actual counts were made on the eggs of three fish and these are shown in Table XIV, compared with calculated counts on the same fish. The difference between the two counts in each is small.

TABLE XIV. Comparisons between actual and calculated egg counts.

Fish no.	Cal. count	Actual count	Difference	% difference
38 (1950)	3,107	3,130	-23	-0.73
310 (1951)	3,652	3,618	+34	+0.93
334 (1951)	3,734	3,765	-31	-0.82
				+0.62

In Table XV are given egg counts from 23 maturing char, compared with egg size, fish length, fish weight and fish age (when determined). The mean maturing egg count from these fish, ranging in length from 49 to 66.5 cm., and averaging 56 cm., was 3,589.

In Figure 22 maturing egg counts are compared with fish length. Within this sample there is an increase in the number of eggs with the growth of the fish.

TABLE XV. Maturing egg counts from 23 char, 1950 and 1951.

Fish no.	Egg number	Egg diameter	Fish length	Fish weight	Fish age
		<i>units</i>	<i>cm.</i>	<i>lbs.</i>	<i>winters</i>
214	2,256	62.6	53.0	3.5	..
310	3,618	68.4	53.5	3.9	14
334	3,765	51.0	58.0	5.9	19
340	2,338	56.6	49.0	3.0	..
471	2,696	60.0	53.5	3.4	16
6	2,323	41.4	49.5	2.2	16
505	5,158	64.4	64.5	6.7	..
29	3,511	38.8	50.5	2.8	15
472	3,366	61.4	58.0	4.4	15
222	5,367	52.2	61.5	6.6	21
71	4,218	44.4	62.5	5.9	17
419	2,507	59.0	52.0	4.3	17
487	4,355	59.8	65.0	6.3	15
452	2,816	53.0	49.5	3.3	..
508	2,173	59.2	46.5	2.3	..
342	3,049	51.4	53.0	3.6	..
476	2,745	53.0	52.0	3.7	..
608	4,687	67.4	62.5	4.6	16
278	4,716	51.8	60.0	5.2	13
447	7,223	37.4	66.5	6.9	..
488	3,653	71.8	55.5	4.4	22
184	2,896	63.0	53.0	...	17
38	3,130	56.4	58.0	...	19
	3,589	55.8	56.0		

The ovaries of eight specimens were collected from George River on July 23, 1951, and the eggs from these were measured in the same manner as the Sylvia Grinnell char, above. Of these eight char, six appeared to be maturing for spawning in the autumn of 1951, many of their eggs being definitely enlarged, up to 45.2 units (2.9 mm.) in diameter, and yolky. The largest eggs of the other two specimens averaged 32.4 units (2.1 mm.) and 30.0 units (1.9 mm.) in diameter, were light in colour, with only a small amount of yolk, and were only slightly differentiated from the small, white eggs in the ovaries. In Table XVI are shown egg diameters compared with lengths and ages of the maturing fish. Assuming maturation of at least the six fish with large eggs, it is probable that the George River char are mature as small at least as 37.5 cm. in length, and at as early an age as 7 winters; therefore that they mature at a smaller size and much younger than the Sylvia Grinnell River char.

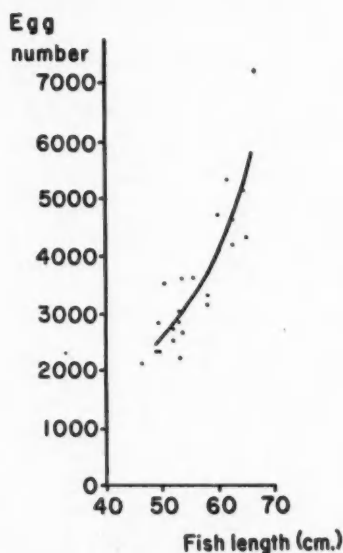


FIGURE 22. The relationship between the number of maturing eggs per fish and fish length.

TABLE XVI. Maturing egg diameters (in 0.064-mm. units) and egg counts of George River char, 1951.

Specimen no.	Fish length	Fish age	Egg diameter	Egg count
	<i>cm.</i>	<i>winters</i>	<i>units</i>	
1	41.5	7	42.1	2,455
4	42.5	9	44.3	2,596
7	42.0	7	45.2	2,646
9	43.5	7	45.2	3,039
11	43.5	8	41.6	3,266
12	37.5	7	44.6	2,352
	41.2		43.8 (2.8 mm.)	2,726

Counts were made on the eggs of six of the George River char which appeared to be maturing when collected. The method of counting was the same as was applied to the Sylvia Grinnell char, above. Egg counts are given in Table XVI, above, and are compared with fish length and age, and egg size.

The mean count was 2,726 eggs per fish of an average length of 41.2 cm., which is comparable to the egg count from the Sylvia Grinnell char of about 52 cm. in length. While no specimens of greater than 45 cm. in length were collected from George River, so that a direct comparison of maturing egg counts from fish of the same length cannot be made between specimens of the two regions, there is a suggestion of a higher relative fecundity (number of eggs per unit of fish length) in George River than in the Sylvia Grinnell River.

TABLE XVII. Food specimens taken from *Salvelinus alpinus* of Frobisher Bay in 1948, 1950 and 1951.

Food species	No. taken	Date
<i>Themisto libellula</i> (Mandt)	3,410	all years
<i>Themisto</i> sp.	305	"
<i>Hyperia medusarum</i> (O. F. Müller)	5	July 29, Aug. 2, 1948; Aug. 20 and 22, 1950
<i>Hyperia galba</i> (Mont.)	1	Aug. 6, 1950
<i>Pseudalibrotus littoralis</i> (Krøyer)	14,406	all years
<i>Pseudalibrotus</i> sp.	34,760	"
<i>Anonyx nugax</i> (Phipps)	2	Aug. 19, 1950
<i>Anonyx</i> sp.	1	Aug. 1, 1950
<i>Orchomenella minuta</i> (Krøyer)	3	Aug. 7, 1950
<i>Gammarus</i> sp.	1006	all years
<i>Gammaracanthus loricatus</i> (Sabine)	17	"
<i>Pontoporeia affinis</i> Lindström	525	"
<i>Apherusa glacialis</i> (H. J. Hansen)	28	"
<i>Ischyrocerus anguipes</i> Krøyer	3	July 24, 1948
<i>Calanus hyperboreus</i> (Krøyer)	699	all years
<i>Calanus finmarchicus</i> (Gunnerus)	183	"
<i>Pareuchaeta glacialis</i> (H. I. Hansen)	3	Aug. 6, 1948
<i>Pareuchaeta norvegica</i> (Boeck) ?	1	Aug. 8, 1951
<i>Mysis oculata</i> (Fabricius)	2,855	all years
<i>Mysis mixta</i> Lilljeborg	111	1950 and 1951
Small mysids (unidentified)	746	all years
<i>Thysanoessa inermis</i> (Krøyer)	34	"
<i>Thysanoessa raschii</i> (M. Sars)	2	Aug. 20 and 22, 1950
<i>Thysanoessa</i> sp.	1	1950
Cladocera (unidentified)	3	July 22, 1948
Isopoda (unidentified)	1	1950
<i>Lebbeus groenlandicus</i> (Fabricius)	16	1950
<i>Argis dentata</i> (Rathbun)	6	1950
Decapod larvae (unidentified)	183	all years
<i>Nereis pelagica</i> Linn.	16	1948
<i>Nereis</i> sp.	100	all years
Chaetognatha (unidentified)	75	Aug. 26, 1951
Diptera (unidentified)	35	1951
Insect larvae (unidentified)	131	1951
<i>Salvelinus alpinus</i> (Linn.)	3	July 4 and 10, 1951
<i>Myoxocephalus groenlandicus</i> (Cuvier and Valenciennes)	111	all years
<i>M. groenlandicus</i> ?	200	all years
<i>Triglops pingeli</i> Reinhardt	6	July 7 and 11, 1951
<i>T. pingeli</i> ?	7	1951
Small sculpins (unidentified)	220	all years
<i>Eumicrotremus spinosus</i> (Müller)	5	1950 and 1951
<i>Liparis</i> sp.	4	1951

FEEDING HABITS

Analysis was made of the stomach contents of about 490 char from Frobisher Bay, Adlirilik in eastern Ungava Bay, George River in southeastern Ungava Bay, and Herschel Island, N.W.T. In all about 60,900 food specimens were examined, comprising at least 34 species.

About 450 char stomachs from Frobisher Bay were examined, and were found to contain some 60,200 food specimens representing at least 30 species. These collections were made in 1948, 1950 and 1951, between June 26 and September 5. Table XVII lists the species which were found, all recorded previously from northern waters.

TABLE XVIII. Food species taken from a specimen of *Salvelinus alpinus* caught on July 4, 1951, at Adlirilik, eastern Ungava Bay, by the Fisheries Research Board vessel *Calanus*.

Food species	No. taken
<i>Themisto libellula</i> (Mandt)	13
<i>Hyperoche medusarum</i> (Krøyer)	1
<i>Pseudalibrotus littoralis</i> (Krøyer)	49
<i>Apherusa glacialis</i> (H. J. Hansen)	16
<i>Westwoodilla megalops</i> (G. O. Sars)	2
<i>Thysanoessa inermis</i> (Krøyer)	1
Decapod larvae (unidentified)	200
<i>Myoxocephalus groenlandicus</i> (C. & V.)	2
Small sculpins (unidentified)	200
<i>Ammodytes</i> sp.	3
<i>Liparis</i> sp. ?	3

TABLE XIX. Food species taken from 13 specimens of *Salvelinus alpinus*, collected on July 23, 1951, at George River, southeastern Ungava Bay, by M. J. Dunbar.

Food species	No. taken
<i>Themisto libellula</i> (Mandt)	6
<i>Calanus hyperboreus</i> (Krøyer)	1
Decapod larvae (unidentified)	5
Small sculpins (unidentified)	4
<i>Triglops pingeli</i> Reinhardt	2
<i>Ammodytes</i> sp.	24

TABLE XX. Food species taken from 23 specimens of *Salvelinus alpinus* collected by A. H. Lawrie at Herschel Island, N.W.T., between August 17 and 19, 1951.

Food species	No. taken
<i>Themisto libellula</i> (Mandt)	75
<i>Hyperia medusarum</i> (O. F. Müller)	1
<i>Gammarus</i> sp.	2
Decapod larvae (unidentified)	6
<i>Myoxocephalus groenlandicus</i> (C. & V.)	76
<i>Boreogadus saida</i> (Lepechin)	1

SUMMARY

1. As a result of the methods used in fishing for the Arctic char in Frobisher Bay, in 1948, 1950 and 1951, inadequate sampling resulted in the taking of a disproportionately small number of specimens between 15 and 20 cm., and none between 20.5 and 26.5 cm. in length, and necessitated the estimation of a calculated growth curve.

2. The calculated curve was constructed by showing the relationship between fish length and otolith width and expressing it in the form of the equation, $\log(\text{fish length}) = -1.503 + 1.982 \log(\text{otolith width})$. From otolith-ring measurements the relationship between otolith width and fish age was determined, and these values were substituted in the equation above to give a calculated fish length for each year, expressed as lengths at the ends of winters.

3. Close agreement is shown between the observed and calculated lengths except in the 6-, 7-, 8-, 9- and 10-winter specimens, which had been sampled in a non-random fashion.

4. The char of Frobisher Bay show increasing yearly growth increments until the end of the ninth winter, after which time the rate of growth diminishes yearly.

5. Males show a more rapid growth than females after about 12 winters.

6. Weight increase occurs in the char during the summer period spent in the sea. This increase is greater than the addition in weight of the gonads, and indicates an improvement in the condition of the fish. The weight of males exceeds that of females after about 12 winters.

7. The Arctic char of George River and Herschel Island show a more rapid growth rate than the Frobisher Bay population.

8. The Arctic char of Svalbard grow more rapidly than those from Frobisher Bay, while the char of western Greenland appear to grow at a rate intermediate to the Svalbard and Frobisher Bay populations.

9. The first migration to the sea of the Sylvia Grinnell char probably occurs for the most part during the fifth, sixth and seventh summers. Seaward migration takes place in late spring, most of it probably before the ice has broken about the river mouth. The return to fresh water begins in late July or early August and continues until at least early September, and its occurrence seems to be influenced by tidal conditions, most upstream movement taking place at high tides, and the first mass upstream migration beginning during high spring tides.

10. The length at maturity of the Sylvia Grinnell char is about 45 cm. Maturity occurs in the Sylvia Grinnell River at about 12 winters, and in George River at least as early as 7 winters, possibly younger. About 33 per cent of the Sylvia Grinnell char of 45 cm. and longer were in condition for spawning in the autumn of 1951. The char of the Sylvia Grinnell show a lower relative fecundity than those of George River.

11. At least 34 food species were taken from the Arctic char of Frobisher Bay, Adlirilik, George River and Herschel Island.

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